TRANSACTIONS

of the

American Foundrymen's Association

Proceedings of the

Thirty-ninth Annual Meeting

Toronto, Ont.

August 20 to 23, 1935

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EDITED BY
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Annual Address

By President D. M. Avey

Presented at Opening Meeting, Toronto Convention, August 20, 1935

The foundry industry is midway in a transition period. Like all manufacturers, foundrymen face economic, political and industrial crises which they cannot surmount alone. Upon their ability to meet and solve the pressing problems which confront them, depend their individual fortunes, the future of the industry and the progress of all the contributory and dependent industries. The obstacles are too great and the pressure of rapidly changing forces in business today are beyond the power of the individual to overcome. It is only through cooperation, intelligent leadership and equally enlightened ability to choose and follow that survival is possible.

While the post-depression period, through which we slowly advance is charted by many experiences of the past, new conditions and certain obvious lessons deserve study. Adversity, the hard teacher, has left scars of the rod, but resources have accrued and new tasks are set which demand attention. A quick review and reading tomorrow's problems from the blackboard is in order.

Depression has depleted finances. We can recall that the era characterized by profitless prosperity merged into the sudden and disastrous world-wide depression. The period following taxed treasury endurance and starting in 1932 the slow backward climb. foundries have found that the need for finance has been most acute.

Obsolescence

In the foundry industry, with few notable exceptions, plant facilities are inadequate. Obsolescence and wear have taken toll while lack of confidence and financial stringency have prevented even normal machinery replacements. It is doubtful today whether the foundry industry of North America would be capable of producing tonnages to meet normal requirements, while any exceptional demand induced by sudden prosperity or war-time requirements would find the entire industry hopelessly under-equipped. Economy, efficiency, safety and health considerations all add to the pressing demand for improving plant facilities. Even those

new and effective means now offered to improve plant cleanliness and promote health are not as widely purchased and used as they should be.

TECHNICAL ADVANCE

Technical accomplishments, by strange contrast, have moved steadily ahead in the past six years. In this, the foundry industry can take some pride and comfort. Improvements in materials, practices and products, as reflected in the committee reports and proceedings of the A.F.A., constitute a fine record. With this surge of technical advance, certain negative factors are encountered. The question of specifications for cast materials is vital. High specifications broaden markets and are necessary to maintain or gain ground against competitive products. However, unusual, individual and oppressive specification requirements should be resisted and their worth tested and judged by impartial testing organizations cooperating with the American Foundrymen's Association, in the interest of castings producers, consumers and the public.

RESEARCH

The foundry industry cannot afford to be complacent in its attitude toward technical advancement. Well organized industries. with centralized capital and manufacturing facilities, are embarking upon extensive research projects. All of these have in mind broadening markets, and many of these markets at present are found within the foundry industry. While the A.F.A., by reason of its economical administration, offers no means for direct promotion of research activities, it does have under the present structure facilities for organizing and directing individual projects to the benefit of groups or classes of cast products.

The A.F.A. also enjoys such relationships with public and private research organizations that it often can secure and make available directed effort on specific research projects. A further advantage of this phase of the association's work is the ability to further a specific research project and on its completion to report the findings, close the case and discontinue expense.

Foundry business practices in the States have improved, due to self-analysis and a certain measure of ethical self-improvement. Some of this may be credited to codes, but whether to the rehearsal and formal adoption of better trade practices or to the improvement which always results from acquaintance and contact among competitors is debatable. However, a critical period is ahead. The

reaction from attempted dictatorial control always swings the pendulum too far toward the removal of all self-restraint. Intelligent business judgment dictates the need for uniting through trade associations to improve trade practices, to secure intelligent pricing based on proper costs.

COMPETITION

Competitive relationships between the various classes of cast products always will exist. To deny them, in the twilight zone which marks overlapping properties attainable by various cast products, is idle.

However, the closeness of relationship between gray iron, steel, malleable, and nonferrous casting and the encroachment upon all by other fabricated products should effectively prevent destructive competition between branches of the industry. The entire foundry industry faces competition from without not only from rolled, welded, formed and forged metals but from plastics and other synthetic products. Accordingly, the need for unity in the foundry industry is paramount. Improvement in castings design, manufacture, and application in each and every branch measures the progress possible for all. Problems of management, manufacture, materials and personnel can best be met and solved by united effort of the entire industry.

APPRENTICESHIP

All industry is under-recruited in man power. The foundry industry in common with all others lacks trained men. The drift away due to unemployment, the toll of increasing average age uncompensated by normal training opportunities during the past five years leave a tremendous gap in the ranks.

The foundry industry never has been notable for organized and sustained apprenticeship effort. Even though it had been, the depression probably would have destroyed such effort.

Now more than ever in the history of the industry is this lack deplorable. The problem of attracting and training young men to become molders, coremakers, patternmakers, melters and mechanics is immediate. Similarly, the training of foremen and superintendents is a vital need. Such men cannot be found in sufficient numbers to supply the needs today, and tomorrow their absence may be disastrous. Organized systematic means must be found to give such men their opportunity to learn and provide for the industry the man power which it will require.

The day has passed when training may be left to chance. Nor will the future provide for each that he may replenish his workmen from the shops of his competitors. In the competition for trained men, hard to visualize in these days of huge unemployment totals, the foundry industry will be at a loss. The pride of craft no longer draws ambitious boys. The inbred love for soft living, the attraction of clean shirt trades and white collar pursuits diminish the available supply of the next generation's foundrymen. These conditions are not new. They are magnified, and built to towering height by the times, the chatter of politicians which teaches that men may live without labor. The theory that every man is a king may catch votes, but it makes no castings.

Therefore, the job of encouraging apprentices and offering them a tangible, productive and useful means of life is the job most vital to the foundry industry. It cannot be accomplished by sporadic effort. The failure of abortive, isolated and individual attempts multiplies the difficulties. The problem can and should be tackled under a national, united plan, built upon the policy that an education will be made available to young men, which will equip them for a profitable life of employment.

Program Available

The approved apprenticeship program prepared and promoted by the American Foundrymen's Association in cooperation with the National Founders' Association is a guide to elementary training. This plan and detailed program was supplied to the industry early this year. The publications of the A.F.A. constitute a reference and working library for foundry executives. Meetings and courses in sectional and chapter meetings offer a further aid to fundamental foundry training. All these available aids to training men are valuable, will be used and will serve, but they are not sufficient to the immediate pressing need. Effort should be consolidated and intensified. Then for the next step.

Executive Training

The problem of training men for major executive responsibility in the foundry industry is not new, although probably more pressing today than in the past. It cannot be solved by taking college trained engineers, for reasons well known to educators, although exceptions will be found. Speaking at the annual banquet of the

association in Cleveland in 1930, Dr. William E. Wickenden, president of Case School of Applied Science, said:

> "If you look to the colleges and universities which carry men on through a period of four or more years of continuous education beyond the high school, expecting them to finish at the age of twenty-two or twenty-three, invested with the rights and insignia of professional degrees, invested with some sense of professional consciousness and of obligation to dignity, if you look to that group largely to go back to industry and begin in overalls and climb the ladder which leads from the work of production through foremanship, through the lesser grades of superintendency, to the higher grades of superintendency and management, I fear you may look in vain. * * *
>
> "If a young man is kept from active, responsible contact with the productive processes of industry until the age of twenty-three, the likelihood of starting him at the beginning of that ladder of line organization and operating responsibility is, I regret to say, a rather small one. * * *
>
> "Until we can match up these institutions which we now have, with others which are specifically devoted to the task of preparing a great body of young men chosen from the working ranks of industry itself for the higher practical and higher operating responsibilities of the industry, we may possibly be doomed to disappointment in our hopes for the man power upon which every one of our industries depends.
>
> "There is another aspect of the thing as well. It has long been recognized, universally, that it is impossible for any man to complete a satisfactory education for technical and scientific professions in a college. Education for those purposes cannot be carried to completion in a college. We have before us a great task of adding another stage, another chapter built up on the base so that it can be produced within the college itself carried on into the early years of the professional and industrial career, to capture the first five or ten years of the young man's participation in industry for the completion of his education."

Another line of thought, equally provocative of imagination as that advanced by Dr. Wickenden, is the possibility of providing courses in our educational institutions specifically directed to training foundry minor executives. England has made a start in this direction through the establishment of a school to train foremen for superintendencies, at the Birmingham Central Technical College. A one year course is offered with tuition set at $150 for those that complete the work with the selection of men recommended and with the support of a group of organizations united with the Institute of British Foundrymen. Perhaps such a plan might be

established with the support of the American Foundrymen's Association and with perhaps a number of different universities.

HEALTH

Yet another problem which should be tackled by a united foundry industry is that presented by the silicosis situation. Resistance of unwarranted attack by the racketeering element of the legal profession has been ably handled in the past few years, and this phase is passing. However, the fundamental questions of proper safeguards, dust prevention equipment, insurance, and compensation legislation remain. Much will be heard on this subject during this convention. It is sincerely hoped that the foundry industry will tackle these problems, constructively and effectively through the American Foundrymen's Association in cooperation with other organizations of the industry.

A.F.A. ACCOMPLISHMENTS

The American Foundrymen's Association in the present transition period is vital to the foundry industry as a whole.

Its fine record of accomplishment must be continued and broadened to meet new responsibilities. The work of instruction through its conventions and exhibitions is but a continuation of its past achievements. The A.F.A. has led in the improvement of qualities that fostered the wider use of castings. It has encouraged and promoted activities of the trade associations which serve individual product classes of the industry. It has acknowledged and assumed a responsibility in advancing the cause of castings in competition with the products of other types of fabrication. It has led and advised in the merchandising of all castings through assembling data, actively promoting specifications satisfactory and beneficial to foundries, it has worked with engineering societies and groups of consumers in promoting the wider use of castings. The Association has cooperated in the problem of training from the elementary stage of apprentice education through to the collection and dissemination of technical knowledge sought by superintendents, metallurgists and executives. In cooperation with equipment and supply manufacturers, the A.F.A. has furthered advancement of the industry in plant facilities and equipment. It has worked quietly but effectively in many important ways in the silicosis agitation.

All of this is familiar to loyal and active members of the Association.

The entire industry benefits from these accomplishments. Even those who are not members or who are remote from normal influence of its work receive some benefits. Those who attend the annual conventions and exhibits secure greater profit. But, those who engage in the work of committees, in preparing papers and in discussion on the convention floor profit most.

Chapter Movement

It is with the thought of multiplying these opportunties for personal and individual profit to foundrymen that the local chapter idea has been launched and furthered. Four now are established in Chicago, Cleveland, Philadelphia and the Moline, Davenport, Quad City area. Many more are in the formative stage.

To multiply the opportunities afforded by the A.F.A. and to secure for the industry a greater measure of advancement is the purpose of local chapters. They serve to tie together more closely the interests of the industry. Through local chapter meetings, new talent is unearthed and hesitant ability is brought out from the crowd.

Participation in local chapter activity makes of every foundryman a better man for himself, his company and the industry.

The activity of local chapters permits handling more effectively those questions relating to technical advance, training and education. Herein lies the greatest opportunity for the foundry industry and for those who are bound to it by destiny.

Report of Secretary-Treasurer

By C. E. Hoyt

Presented at Opening Meeting—Toronto Convention
August 20, 1935

For the fiscal year closed June 30, for the first time in three years we show income in excess of expense. The amount was small but it very definitely indicates that having struck bottom, we are steadily climbing. According to the balance sheet of the auditor, Robert T. Pritchard, Cash, Accounts Receivable and Supplies on Hand total $2,642.71. The book values of investments in our Reserve Fund is $21,705.55. The market value of these investments at date of audit, July 29, was $20,651.50. In a Special Steel Casting Test Fund we have a balance of $312.58. The auditor's report shows that our income was $1,726.30 in excess of expense as against a deficit of $3,249.10 for the year ending June 30, 1934. Prospects are good for a much better showing at the close of this year. In the collection of dues we are now well ahead of a year ago.

Our Award Fund investments have a book value of $21,520.10; the market value of these investments at the date of audit was $22,112.00, an appreciation of $591.90. Total cash in all funds plus market value of all investments is $48,276.62.

The auditor's report with balance sheet as of June 30, 1935 is given on pages xxxvi to xxxviii.

Membership, like finances, has taken a right about face and, for the first time since 1930, we show a gain in numbers on June 30 over June 30 of the previous year. The prospects for membership gains during the present year are good.

We will be staging during this fiscal year two annual conventions, this one and another in May 1936. These two major activities will give us momentum, publicity and a wealth of material for use in selling A.F.A.

Our greatest asset will, however, undoubtedly be the recently organized Chapter Organization Movement. For 38 years, A.F.A. operated without having any affiliated locals or chapters. In January of last year the members ratified amendments to the By-Laws authorizing the organization of chapters wherever there were a sufficient number of members in a given locality interested in holding regular meetings for promoting association objectives. The By-laws also make provisions for financial support of activities

through the refund of dues for that purpose. This work was launched at a time when, as one member recently put it, all industry was "association saturated." However, we now have four chapters thoroughly organized and operating. One in Chicago, one in Cleveland, one in Moline, Rockford and Davenport, and one in Philadelphia, with fair prospects for at least four more chapters being organized early this fall.

Chapter activities are close to the hearts of President Avey and Vice-President Johnson and I am going to leave it to President Avey to visualize their possibilities. I hope he will also have something to say about Apprentice-Training Work which we are carrying on through our Apprentice Committee in cooperation with the National Founders' Association.

We are better organized than ever before to render service to members and to the whole castings industry. We are also better equipped for the getting of necessary funds with which to do this and with the continued cooperation of our members we will get them.

We have stronger and more helpful alliances with other technical and engineering societies. Outstanding perhaps are the cooperative relationships with the American Society of Testing Materials in the developing of specifications for castings and in the joint publication of Casting Symposia.

Joint meetings with local sections of American Society of Mechanical Engineers, with local engineering societies and with the engineering departments of universities and colleges for the purpose of promoting casting uses have been held during the past year and will be continued.

A.F.A. is generally recognized as the one national technical association of the foundry industry representing all branches, gray iron, steel, malleable and nonferrous and as the champion of cast products in healthy, honest competition with other materials.

For that purpose, A.F.A. presents to industry at this convention the first Handbook on Cast Metals ever published in this country.

It is natural that we should hope for a definite increased interest on the part of Canadian Foundrymen as a result of staging this meeting in Canada. On Wednesday of this week a meeting of Canadian Members of A.F.A. will be held. It is hoped that at that meeting some action will be taken providing for some type of organization for Canadian members of A.F.A.

Summary of Proceedings of the 39th Annual Meeting

The Thirty-Ninth Annual Convention of the American Foundrymen's Association was held in Toronto, Canada, August 20-23, 1935, at the Royal York Hotel. Although this convention was held without an exhibit, over 1,000 foundrymen from both the United States and Canada were registered and participated in the technical sessions and social events of the week.

The enthusiasm evidenced both at the technical sessions and various functions, stamped this convention as one of the best of its kind ever held in the history of the Association. There were 26 technical sessions consisting of nine on cast iron, malleable iron, steel and non-ferrous founding; six shop operation courses, three each on cast iron and sand control; seven general interest sessions on foundry sand research, refractories, materials handling and foundry equipment, dust control, foundry costs, apprentice training and health hazards and employer responsibility; and four round table luncheon conferences, one each on steel, malleable, cast iron and non-ferrous foundry practice.

Only one exchange paper was presented this year, that of the Institute of British Foundrymen. In all, 38 papers and a large number of reports of various committees were presented. In addition to the usual technical sessions, a large number of committee meetings were held.

An outstanding feature of the convention was the session on "Health Hazards and Employer Responsibility," at which Dr. Wm. J. McConnell, Assistant Medical Director and Director, Industrial Health Section, Metropolitan Life Insurance Co., New York, and Donald L. Cummings, Field Director, Saranac Laboratory, Saranac Lake, N. Y., two outstanding authorities on industrial health, were the speakers.

Plant visitations were made a prominent activity of the week and the Toronto Plant Visitation Committee, under the chairmanship of Melville P. White, Canadian General Electric Co., proved very efficient in aiding the members to see the many interesting foundries operating in the Toronto territory.

The visiting ladies were entertained most pleasantly at teas at the Royal Canadian Yacht Club and the Granite Club by the

Canadian Foundry Committee, which was under the chairmanship of D. B. McCoy, Steel Co. of Canada, Ltd. The ladies of the Toronto Committee proved most delightful hostesses and made the convention outstanding in the history of the Association.

The Toronto committees were directed by a General Committee under the chairmanship of Major L. L. Anthes, Anthes Foundry, Ltd., Toronto, a past president of A.F.A. The convenor of committees was John T. Hepburn, John T. Hepburn, Ltd., Toronto.

Details of the various sessions follow:

OPENING SESSION

Tuesday, August 20, 10:00 A. M.

Presiding: Dan M. Avey, President, American Foundrymen's Association.

President Avey, after announcing the formal convening of the 39th Annual Convention, introduced Major L. L. Anthes, Past President of the A.F.A. and Chairman, Toronto Convention Committee, who gave an address of welcome to assembled members and guests of the Association. President Avey responded on behalf of the Association. C. E. Hoyt, Executive Secretary, then gave a brief report of the activities of the Association during the past year. This report is reproduced on pages xii and xiii. Following Secretary Hoyt's report, Frank G. Steinebach, Chairman of the Committee on International Relations, read messages of greeting from the Institute of British Foundrymen and the Association Technique de Fonderie, the French Foundry Technical Association.

President Avey then presented the annual presidential address which appears in this volume, pages v to xi.

CAST IRON FOUNDING

Tuesday, August 20, 11:00 A. M.

Chairman—H. Bornstein, Deere & Co., Moline, Ill.

Vice Chairman—V. A. Crosby, Climax Molybdenum Co., Detroit.

The following papers were read and discussed:

Impact Resistance and Other Physical Properties of Alloy Cast Iron, by Garnet P. Phillips, International Harvester Co., Chicago, Ill.

Heat Treatment of Cast Irons, by R. G. McElwee, Ecorse Foundry Co., Ecorse, Mich.

A Study of an Industrial Application of the Martensitic Transformation of Austenitic Iron, by G. R. Delbart, Denain, France. In absence of the author, this paper was presented by J. S. Vanick, International Nickel Co., Inc., New York.

FOUNDRY SAND RESEARCH

Tuesday, August 20, 11:00 A. M.

Chairman—H. B. Hanley, American Laundry Machinery Co., Rochester, N. Y.

The following paper was presented and discussed:

The Expansion and Contraction of Molding Sand under Elevated Temperatures, by H. W. Dietert, and F. Valtier, H. W. Dietert Co., Detroit, Mich.

Dr. H. Ries, Cornell University, Ithaca, N. Y., read a progress report on the activities of the Foundry Sand Research Committee.

W. G. Reichert, Singer Mfg. Co., presented a report of the Subcommittee on Grading of Foundry Sands with reference to the distribution factor.

H. W. Dietert, H. W. Dietert Co., Detroit, presented the report of the Subcommittee on Durability of the Committee on Tests.

REFRACTORIES

Tuesday, August 20, 8:00 P. M.

Chairman—C. E. Bales, Ironton Fire Brick Co., Ironton, O.

The following papers were presented and discussed:

Some Uses of Insulating Refractories in Modern Foundry Practice, by C. L. Norton, Babcock & Wilcox Co., New York, N. Y. In absence of the author, this paper was presented by the Chairman.

Malleable Furnace Refractories, by L. C. Hewitt, Laclede-Christy Clay Products Co., St. Louis, Mo. In absence of the author, this paper was presented by M. A. Hosmer, Hunt-Spiller Mfg. Corp., Boston, Mass.

SAND SHOP COURSE (Session 1)

Tuesday, August 20, 8:00 P. M.

Chairman—Neil I. McArthur, Great Lakes Foundry Sand Co., Detroit, Mich.

Subject—New Sand Qualities.

Discussion Leader—G. F. Pettinos, George F. Pettinos, Inc., Philadelphia, Pa.

CAST IRON SHOP COURSE (Session 1)

Tuesday, August 20, 9:00 P. M.

Chairman—Fred J. Walls, International Nickel Co. Inc., New York.

The following papers were presented and discussed:

Relation of the Air Change to Cupola Operation, by H. V. Crawford, General Electric Co., Schenectady, N. Y.

The Control of Cupola Operation, by H. L. Campbell and J. Grennan, University of Michigan, Ann Arbor, Mich. This paper was presented by Mr. Grennan.

MALLEABLE CAST IRON

Wednesday, August 21, 9:00 A. M.

Chairman—R. J. Teetor, Cadillac Malleable Iron Co., Cadillac, Mich.

Vice Chairman—A. M. Fulton, Northern Malleable Iron Co., St. Paul, Minn.

The following papers were presented and discussed:

Endurance Tests of Malleable Iron, by E. G. Mahin, University of Notre Dame and J. W. Hamilton, Bendix Products Corp., South Bend, Ind. The paper was presented by Dr. Mahin.

Notes on the Production of Cupola Malleable Iron Fittings, by F. B. Riggan, Stockham Pipe & Fittings Co., Birmingham, Ala. In absence of the author, the paper was presented by H. C. Aufderhaar, Electro Metallurgical Co., Chicago, Ill.

Dr. H. A. Schwartz, National Malleable & Steel Castings Co., Cleveland, O., presented the report of the Committee on Specifications for Malleable Iron.

MATERIALS HANDLING AND FOUNDRY EQUIPMENT

Wednesday, August 21, 9:00 A. M.

Chairman—James Thomson, Continental Roll & Steel Foundry Co., East Chicago, Ind.

Vice Chairman—Pat Dwyer, *The Foundry*, Cleveland, O.

The following papers were presented and discussed:

Mechanical Handling of Sand and Castings for Small Tonnage Plants, by E. W. Beach, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

Mechanical Charging for Small Tonnage Foundries, by D. J. Reese, Whiting Corp., Harvey, Ill.

CAST IRON FOUNDING

Wednesday, August 21, 11:00 A. M.

Chairman—Dr. J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Vice Chairman—W. H. Spencer, Sealed Power Corp., Muskegon, Mich.

The following papers were presented and discussed:

Structure and Properties of Gray Cast Iron, by A. DiGiulio, Ford Motor Co., Detroit, and A. E. White, University of Michigan, Ann Arbor, Mich. Presented by Dr. DiGiulio.

Progress in the Production of Gray Cast Iron for Locomotive Parts, by A. Reyburn, Canadian National Railways, Montreal, Canada.

OPEN MEETING OF FOUNDRY COST COMMITTEE

Wednesday, August 21, 11:00 A. M.

Chairman—Sam Tour, Lucius Pitkin Inc., New York.

This meeting was devoted to a general discussion and comparison of the cost systems of the various foundry trade associations.

INDUSTRIAL HEALTH HAZARDS AND EMPLOYER RESPONSIBILITY

Wednesday, August 21, 8:00 P. M.

Chairman—President D. M. Avey, The Foundry, Cleveland, O.

The following two outstanding authorities spoke on the above subject:

Dr. Wm. J. McConnell, Assistant Medical Director, and Director, Industrial Health Section, Metropolitan Life Insurance Co., New York.

Donald L. Cummings, Field Director, Saranac Laboratory, Saranac Lake, N. Y.

CAST IRON SHOP COURSE (Session 2)

Wednesday, August 21, 8:00 P. M.

Chairman—John Grennan, University of Michigan, Ann Arbor, Mich.

The following paper was presented and discussed:

Adding Ferro-Alloys in the Cupola, by E. K. Smith and H. C. Aufderhaar, Electro Metallurgical Co., Chicago, Ill. Presented by Mr. Aufderhaar.

SAND SHOP COURSE (Session 2)

Wednesday, August 21, 9:00 P. M.

Chairman—H. W. Dietert, H. W. Dietert Co., Detroit, Mich.
Subject—Foundry Sand Problems Where Natural Sands Are Used.
Discussion Leader—Horace Deane, John Deere Co., Moline, Ill.

SAND SHOP COURSE (Session 3)

Thursday, August 22, 9:00 A. M.

Chairman and Discussion Leader — R. F. Harrington, Hunt-Spiller Mfg. Co., Boston, Mass.
Subject—Synthetic Sands.

CAST IRON SHOP COURSE (Session 3)

Thursday, August 22, 10:00 A. M.

Chairman—J. A. Sweeney, Florence Pipe Foundry & Machine Co., Florence, N. J.

The following paper was presented and discussed:

Converter and Cupola Duplexing, by D. J. Reese, Whiting Corp., Harvey, Ill.

APPRENTICE TRAINING

Thursday, August 22, 9:00 A. M.

Chairman—John H. Ploehn, French and Hecht., Inc., Davenport, Ia.

The following papers were presented and discussed:

Fifteen Years of Foundry Apprenticeship at the Falk Corp., by Victor Hydar, Director of Personnel, Falk Corp., Milwaukee, Wis.

Some Suggestions for Starting and Carrying Out a Foundry Apprentice System, by J. E. Goss, Employment Manager, Brown & Sharpe Mfg. Co., Providence, R. I.

NON-FERROUS FOUNDING

Thursday, August 22, 9:00 A. M.

Chairman—Jerome Strauss, Vanadium Corp. of America, Bridgeville, Pa.

THIRD ANNUAL CONFERENCE ON DEOXIDATION AND DEGASIFICATION OF NON-FERROUS CASTING ALLOYS

Deoxidation and Degasification of Nickel-Silvers, by R. J. Keeley. Ajax Metal Co., Philadelphia, Pa.

The "Modifying" Phenomenon and Its Probable Relation to the Properties of Non-Ferrous Alloys, by C. H. Lorig and R. W. Dayton, Battelle Memorial Institute, Columbus, O. Presented by Dr. Lorig.

Report of the Committee on Analysis of Defects, by H. M. St. John, Detroit Lubricator Co., Detroit, was read by Wm. Romanoff, H. Kramer Co., Chicago, Ill.

At the Annual Business Meeting of the Non-Ferrous Division, general reports on the activities of the various committees of the Division during the past year were presented.

STEEL FOUNDING

Thursday, August 22, 11:00 A. M.

Chairman—E. W. Campion, Bonney Floyd Co., Columbus, O.

Vice Chairman—P. E. McKinney, Bethlehem Steel Co., Bethlehem, Pa.

The following papers were presented and discussed:

Contraction and Solidification of Steel for Castings—III—Rate of Skin Formation, by C. W. Briggs and R. A. Gezelius, Naval Research Laboratory, Anacostia, D. C. Presented by Mr. Briggs.

Influence of Temperature Gradients in the Production of Steel Castings, by George Batty, Consultant on Steel Castings, Drexel Hill, Pa. This is the 1935 Exchange paper presented before the Institute of British Foundrymen. In absence of the author, the paper was presented in abstract by John Howe Hall, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

CAST IRON FOUNDING

Thursday, August 22, 11:00 A. M.

Chairman—Max Kuniansky, Lynchburg Foundry Co., Lynchburg, Va.

CENTRIFUGAL CASTING SYMPOSIUM

Production of Centrifugal Gray Iron Castings in Water Cooled Molds, by H. W. Stuart, U. S. Pipe & Foundry Co., Burlington, N. J.

Slush Pump Piston Cores by the Centrifugal Process, by A. E. Falk, D. & M. Machine Co., Torrence, Calif. In absence of the author, this paper was presented by the Chairman.

Cast Iron Pipe Centrifugally Cast in Sand, by J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala.

Centrifugal Castings, by J. E. Hurst, Sheepbridge Stokes Centrifugal Casting Co., Chesterfield, England. In absence of the author, this paper was presented by Dr. MacKenzie.

MALLEABLE ROUND TABLE LUNCHEON

Thursday, August 22, 1:15 P. M.

Chairman—P. C. DeBruyne, Moline Malleable Iron Co., St. Charles, Ill.

Discussion centered around furnace practice and foundry operation in general.

STEEL ROUND TABLE LUNCHEON

Thursday, August 22, 1:15 P. M.

Chairman—A. W. Gregg, Farrel Cheek Steel Foundry Co., Sandusky, O.

The subject which received the most attention at this meeting was standardization of methods of testing steel castings.

NON-FERROUS ROUND TABLE LUNCHEON

Thursday, August 22, 1:15 P. M.

Chairman—Harold J. Roast, Canadian Bronze Co., Ltd., Montreal, Canada.

Defects and methods used to overcome them were discussed. Sample castings were shown to illustrate the principles involved in the correction of defects.

CAST IRON ROUND TABLE

Thursday, August 22, 1:15 P. M.

Chairman—W. H. Spencer, Sealed Power Corp., Muskegon, Mich.

Effects of nitrogen and oxygen were discussed.

ANNUAL BUSINESS MEETING

Thursday, August 22, 4:00 P. M.

President D. M. Avey Presiding

Officers reports were given and new officers elected. Executive Secretary-Treasurer C. E. Hoyt stated that finances and membership were on the upgrade for the first time in four years. The auditor's report, as given by Mr. Hoyt, appears on pages xxxvi to xxxviii of this volume and the secretary's report, on pages xii and xiii.

The report of the 1935 Nominating Committee was read by the secretary. The personnel of the Nominating Committee was as follows:

Past President, E. H. Ballard, General Electric Co., West Lynn, Mass., *Chairman.*

Past President Frank J. Lanahan, Fort Pitt Malleable Iron Co., Pittsburgh, Pa.

Past President T. S. Hammond, Whiting Corp, Harvey, Ill.

J. H. Lansing, Grand Rapids, Mich.

Vaughan Reid, City Pattern Works, Detroit, Mich.

Kieth Williams, Pratt & Letchworth Co., Buffalo, N. Y.

The Nominating Committee presented the names of the following members for officers and directors:

For President To Serve for One Year

D. M. Avey, "The Foundry," Cleveland, O.

For Vice President To Serve for One Year

B. H. Johnson,* R. D. Wood Company, Philadelphia, Pa.

For Directors To Serve for Three Years Each

Lamar S. Peregoy, Sivyer Steel Casting Co., Milwaukee, Wis.

C. E. Davis, Alloy Specialty Co., Coraopolis, Pa.

W. J. Cluff, Fredric B. Stevens, Inc., Detroit, Mich.

Frank A. Sherman, Dominion Foundries & Steel, Ltd., Hamilton, Ont., Canada.

Henry S. Washburn, Plainville Casting Co., Plainville, Conn.

Following the presentation of this report, a motion was made by S. C. Vessy, seconded and unanimously approved

"That the secretary cast the ballot of the Association for those men nominated."

The next report presented was that of the committee to nominate four members to serve with the three immediate past presidents, as the 1936 Nominating Committee. This report read as follows:

"Your committee appointed to nominate four members for election to the 1936 Nominating Committee presents the names of the following members:

A. E. Hageboeck, Frank Foundries Corp., Moline, Ill.

A. E. Walcher, American Steel Foundries, Chicago, Ill.

Dr. H. A. Schwartz, National Malleable & Steel Castings Co., Cleveland, O.

Dr. G. H. Clamer, Ajax Metal Co., Philadelphia, Pa.

Respectfully submitted,

James Thomson, *Chairman*

F. J. Walls

Karl Dodge

Past President A. B. Root, Jr., then moved

"That the report be accepted and the election of these men to the 1936 Nominating Committee be approved."

This motion was seconded and approved.

There being no further business, the meeting adjourned.

ANNUAL BANQUET

Thursday, August 22, 7:00 P.M.

The John A. Penton Gold Medal of the A.F.A. was presented** to Major Lawrence Lee Anthes, Anthes Foundry, Ltd., Toronto, and a past president of A.F.A., by Past President Frank J. Lanahan, Chairman of the Board of Awards.

B. K. Sandwell, managing editor of the Toronto "Saturday Night"

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* Following the death of Vice President Johnson on August 27, the Board of Directors selected Director J. L. Wick, Jr. to fill this vacancy. To complete Director Wick's unexpired term, the Board selected Past President E. H. Ballard.

** Past President Lanahan's presentation address will be found reproduced in TRANSACTIONS, vol. 6, no. 5, October 1935, pp. 7 and 8.

gave the banquet address and was introduced by George C. Crawford, American Radiator & Standard Sanitary Mfg. Co., Toronto.

STEEL FOUNDING

Friday, August 23, 9:00 A.M.

Chairman—John Howe Hall, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

The following papers were presented and discussed:

Utilization of X-rays in the Correction of Foundry Practice and for the Proper Control of Welding of Castings, by C. M. Underwood and E. J. Ash, Naval Gun Factory, Washington, D. C. Presented by Mr. Ash.

Fabrication of Cast and Rolled Steel, by J. M. Sampson, General Electric Co., Schenectady, N. Y.

CAST IRON FOUNDING

Friday, August 23, 9:00 A.M.

Chairman—Walter Seelbach, Forest City Foundries Co., Cleveland, O.

Vice Chairman—R. F. Harrington, Hunt-Spiller Mfg. Co., Boston.

The following papers were presented and discussed:

Wear Resistance of White Cast Iron, by O. W. Ellis, J. R. Gordon and G. S. Farnham. Presented by Mr. Gordon.

Slags and Gases in Cupola Operation, by A. H. Dierker, Ohio State University, Columbus, O. In absence of the author, this paper was presented by Dr. C. H. Lorig, Battelle Memorial Institute, Columbus, O.

The report of the International Committee on Tests was presented by W. H. Spencer, Sealed Power Corp., Muskegon, Mich., A.F.A. representative on the International Committee and consisted of a review of the various reports received from foreign associations.

DUST CONTROL AND SAFETY CODES

Friday, August 23, 11:00 A.M.

Chairman—E. W. Beach, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

The following papers were presented and discussed:

Dust Collection Equipment, by S. D. Moxley, American Cast Iron Pipe Co., Birmingham, Ala.

Methods of Dust Control, by J. D. Leitch, Provincial Department of Health, Toronto, Ont., Canada.

Some Notes on Cloth Dust Arresters, by J. R. Allan, International Harvester Co., Chicago, Ill.

NON-FERROUS FOUNDING

Friday, August 23, 11:00 A.M.

Chairman—James L. Wick, Jr., Falcon Bronze Co., Youngstown, O.

The following papers were presented and discussed:

Founding of Magnesium Alloys, by Dr. J. A. Gann and M. E. Brooks, Dow Chemical Co., Midland, Mich. The paper was presented by Dr. Gann.

High-Strength Non-Ferrous Casting Alloys, by A. J. Murphy, J. Stone & Co., Ltd., Deptford, England. This is the Annual Exchange paper presented on behalf of the Institute of British Foundrymen and in the absence of the author, was presented in abstract by Sam Tour, Lucius Pitkin, Inc., New York.

Report of Board of Directors, Executive Committee and Board of Awards Meetings for the Calendar Year 1935

Following the annual meetings of the Board of Directors, January 12, 1935 and reported in Bound Volume No. 42, the following official meetings were held:

March 4 and 5, Philadelphia—Meeting of Executive Committee.

May 11, Detroit—Meeting of Executive Committee, meeting of Board of Awards, meeting of 1935 Nominating Committee.

August 23, Toronto—Final meeting of the 1934-35 Board of Directors and first meeting of the 1935-36 Board of Directors.

Minutes of Executive Committee Meeting

BELLEVUE STRATFORD HOTEL, PHILADELPHIA, MARCH 4 and 5, 1935

This meeting was held concurrently with the annual committee conferences of the A.S.T.M.

Present: President Dan M. Avey, Vice President B. H. Johnson, Director H. Bornstein, Executive Secretary C. E. Hoyt.

The first item of business considered was a letter by Dr. H. A. Schwartz to W. R. Bean, Chairman, Committee on Definitions for Special Malleable Irons; also a letter by Dr. Schwartz to W. P. Putnam of The Detroit Testing Laboratory, Chairman of Committee A-7 on the subject of Special Specifications for Cupola Malleable. No action was taken on these communications, other than to refer them to the attention of Technical Secretary Kennedy to follow up.

Report of Committee on Mellon Institute Meeting

Consideration was then given to a report prepared by the Temporary Organization Committee appointed to follow up the general industry meeting at Mellon Institute, Pittsburgh, on January 15, called for the purpose of effecting some organization for study of dust hazards in industry. It was the unanimous feeling of those present that the A.F.A. should not subscribe at this time to the program of activities as proposed by the Temporary Organization Committee.

Safety and Health Section of A.F.A.

All were in agreement, however, that some definite effort should be made to coordinate efforts in the study of dust hazards in the foundry industry, and to consolidate movements that have been inaugurated or

that should be inaugurated in various sections of the country to accomplish the following purposes:

To determine the presence of dust hazards and exposure.

Cause and prevention.

Standardization of dust elimination equipment; and improvement of shop operating conditions in the foundry industry, through active educational work covering proper equipment, maintenance, supervision and good housekeeping.

Cooperation with other centralized agencies of industry confronted by similar problems, such as Cement, Refractories, Iron and Steel, Porcelain, Enamel, etc.

Cooperation with all existing reputable agencies where the silicosis problem has been met and solved; and the assembling of information from such sources, applying it where defensive measures are urgently needed by foundries under attack.

Encouragement by active means of the enactment of equitable and fair compensation laws in industrial states, when in the judgment of those interested such is needed.

Promotion of standards for dust elimination and control equipment, in cooperation with agencies of the manufacturers of such equipment.

Discouragement of misguided and damaging publicity material having a tendency to incite or precipitate racketeering attacks; and finally, to work with Public Health Agencies, Insurance Carriers, the Medical and Legal Professions in forwarding health measures and discouraging predatory attacks of those actuated by illicit profit motives.

To accomplish the above objectives, President Avey proposed that consideration be given to organizing a Safety and Health Section of the American Foundrymen's Association. This proposal was given favorable consideration but all were in agreement that to undertake work of this character on behalf of the foundry industry, a full-time director would be required; and further, that it would be necessary to raise funds through subscriptions or contributions to support the work.

It was suggested that this work could be done through an Advisory Board or committee set up under the direction of A.F.A. or in joint sponsorship with other associations, but financed independently for and in behalf of the whole foundry industry.

No definite action was taken, but the President and Secretary were authorized to conduct negotiations with the executives of the National Founders' Association and with such other organizations as in their judgment it would be wise to approach, secure their reactions, and report back to the Executive Committee.

Apprentice Training

Secretary Hoyt called attention to Executive Order No. 6750-C, dated June 27, 1934, creating a Federal Committee on Apprentice Training, stating that this order prompted extending an invitation to William F. Patterson, Executive Secretary of the Federal Committee on Apprentice Training, to deliver an address at their apprentice session at the Philadelphia convention.

Secretary Hoyt recommended that the address of Mr. Patterson,

published in the October number of "Transactions" and transcript of discussion which had been reviewed by Mr. Patterson and others participating, be printed in pamphlet form and made available to all members. This recommendation was approved and printing authorized.

Standards of Four-Year Foundry Apprenticeship

Secretary Hoyt submitted copy of "Standards of Four-Year Foundry Apprenticeship" as prepared jointly in 1930 by A.F.A. Committee on Apprentice Training and the Educational Committee of the N.F.A., but never printed.

It was the recommendation that this work be reviewed and then printed under the joint sponsorship of the A.F.A. and the N.F.A. Members present were unanimous in feeling that this should be done and copies made available not only to all members, but to members of Federal Apprentice Training Committees in the various states, and that industry representatives on these committees be urged to accept these standards wherever foundry apprentice training standards and courses were being considered.

Membership Emblem

Secretary Hoyt submitted designs that had been prepared for an attractive membership emblem. These designs were favorably commented on and the securing of them approved when Association finances would permit.

Without motion this Executive Committee conference stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Meeting of Executive Committee

STATLER HOTEL, DETROIT, MAY 11, 1935

This meeting was preceded by a meeting of the 1935 Nominating Committee, a meeting of the A.F.A. Board of Awards, and a general conference with a delegation from Toronto, headed by Past President L. L. Anthes, General Chairman, Toronto Convention Committee.

The meeting also followed a two-day sectional meeting at East Lansing, sponsored jointly by A.F.A., Detroit Foundrymen's Association, and Engineering Department of Michigan State College.

Because of all of the meetings and activities of the day, the meeting of the Executive Committee was not called until late in the evening.

Members present: President Dan M. Avey, Vice President B. H. Johnson, James L. Wick, Jr., and Secretary C. E. Hoyt. (Directors Frank J. Lanahan and H. Bornstein, who had participated in conferences of the day, left to catch early trains, after having expressed their views on subjects included in the agenda for this Executive Committee meeting.)

Others present: Past Presidents Fred Erb, L. L. Anthes, E. H. Ballard, S. W. Utley; Technical Secretary R. E. Kennedy; E. O. Jones of the N.F.A.; and Frank G. Steinebach, "The Foundry."

President Avey stated that the agenda called for consideration of draft of program for Toronto Convention, but as this had been thoroughly discussed at previous conferences, no further discussion was necessary.

Change in Name of Local Organizations of A.F.A.

Secretary Hoyt reported that there was practically a unanimous desire expressed that the designation of local organizations as provided for in the By-Laws, be changed from "Section" to "Chapter."

Following discussion, it was moved by Vice President Johnson that the designation "Chapter" be accepted; that groups be privileged to organize under that name; and that the Executive Committee recommend to the Board of Directors a change in the By-Laws, providing in their opinion a formal amendment in the usual way was necessary. Motion seconded and unanimously approved.

Apprentice Training

President Avey stated that it had been proposed that a Joint Committee of the A.F.A. and N.F.A. be organized to promote apprentice training.

Mr. E. O. Jones of the N.F.A., who had been invited to this meeting, reported conversations that he had had in Washington with William F. Patterson and Dr. Altmeyer of the Federal Committee on Apprentice Training.

Secretary Hoyt reported that in accordance with Executive Committee authorization, the pamphlet on Apprentice Training, containing the address of Mr. Patterson at the apprentice session, Philadelphia convention, together with the resulting discussion, had been printed and distributed to members of both the A.F.A. and N.F.A., together with copy

of "Standards of Four-Year Apprenticeship" sponsored jointly by the A.F.A. and N.F.A.

It was the opinion of all present that apprentice training was one of the most important activities that A.F.A. could participate in.

President Avey pointed out the possibility of extending the work of the committees on apprentice training, through organizing sub-committees in local Chapters.

President Avey then called on Mr. Jones for a progress report of the Temporary Organization Committee on Dust Hazards set up at a meeting at Mellon Institute January 15, and of which he was a member.

Appreciation was expressed for information presented by Mr. Jones. but it was not thought advisable to take any definite action recommending support by the foundry industry until a formal program had been suggested by the Temporary Organization Committee and carefully considered.

Safety and Health Section of A.F.A.

Secretary Hoyt read from the minutes of the Executive Committee meeting of March 5, reporting consideration given to the organizing of a Safety and Health Section sponsored by the A.F.A. or jointly by A.F.A., N.F.A. and other interested groups or associations.

He reported further that at a meeting of the Board of Awards held this day provision had been made for securing speakers of national reputation for a special evening session on Industrial Health Hazards and Employer Responsibility, at the Toronto convention in August.

In the light of all these reports of plans and programs for meeting this perplexing problem of the industry, it was thought best not to recommend definite action prior to the Board meeting at the annual convention.

President Avey thanked the members of the Advisory Board for their presence and counsel and declared the meeting adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of Annual Meeting of Board of Directors

Royal York Hotel, Toronto, August 23, 1935

This meeting followed the adjournment of the Thirty-Ninth Annual Convention of the Association and was preceded by a luncheon, with the following present:

President Dan M. Avey, and Directors E. H. Ballard, H. Bornstein, R. F. Harrington, R. J. Teetor, J. L. Wick, Jr., E. W. Campion, W. L. Seelbach, Frank J. Lanahan, Sam Tour.

Directors Elect: W. J. Cluff, L. S. Peregoy, H. S. Washburn, C. E. Davis, Frank A. Sherman.

Members of the Advisory Board: L. L. Anthes, A. B. Root, Jr.

Others present: Executive Secretary C. E. Hoyt, Technical Secretary R. E. Kennedy.

Calling the meeting to order, President Avey reported on the illness of Vice President Johnson which had prevented him from participating in any of the meetings of the week. He stated that Mr. Johnson was ill when he arrived in Toronto and that he had been advised to remain in his room and keep quiet. On Monday morning, he had dressed and come downstairs for breakfast, but was prevailed upon to return to his room, when a physician was called and ordered him to bed. On the following day, his condition was apparently more serious, a nurse was engaged, and everything had been done to make him comfortable and improve his condition. However, he had continued to grow worse, and, acting upon the advice of the physician, he had been removed that morning to the hospital for examination and consultation.

It was moved that the Secretary be instructed to convey to Mr. Johnson the Board's sincere regrets that illness had prevented his being with them during the week and their hope for a speedy and complete recovery.

President Avey, addressing Past President L. L. Anthes, General Chairman of Toronto Convention Committees, expressed the appreciation of all for the cordial reception and efficient work of the Chairman and members of his several committees.

Major Anthes, in responding, expressed his appreciation and that of the Canadian members in having entertained a convention of the Association and for the special honors that had been conferred upon him in awarding the John A. Penton Gold Medal of the Association.

Opportunity was given others present to voice their sentiments, and then President Avey called to order the final meeting of the 1934-35 Board of Directors.

On motion, the reading of the minutes of the last Board meeting, which had been published in Bound Volume of "Transactions" No. 42, was omitted.

Minutes of the meeting of the Executive Committee, held at the Statler Hotel, Detroit, May 11, 1935, were read and on motion, duly seconded, were approved.

Reports of Officers

The Chair announced that the report of the Executive Secretary had been presented at the annual business meeting, and a motion would be in order to dispense with the second reading. On motion duly made and seconded, it as so moved.

The report of the Treasurer was read, and on motion, was accepted and referred to the Finance Committee.

The President announced that the reading of the report of the Technical Secretary would be dispensed with, and that copies thereof would be mailed to all Board members.

President Avey announced that in the absence of Vice President Johnson, he had requested Past President and Director E. H. Ballard to serve as a member of the Finance Committee, to serve with the President and the immediate Past President, Mr. Lanahan, Chairman of the Committee.

A report was then called for and presented by Mr. Lanahan, who stated that the Committee had not had an opportunity to make a complete check of the auditor's statement as of July 1 and of the Treasurer's report, and requested that their report be accepted with the understanding that each member of the Finance Committee would submit a written report for the records after making an examination of the auditor's and Treasurer's report. On motion duly made and seconded, the report of the Finance Committee was received.

Chapter Organization

President Avey reported on progress that had been made during the past year in organizing A.F.A. Chapters, which resulted in Chapters being organized in Chicago, Cleveland, Philadelphia and in the Quad Cities, Moline and Davenport.

He further reported that Past Director H. S. Simpson, in making a trip to the Pacific Coast, had acted as an official representative of the A.F.A. and conferred with foundrymen in Los Angeles, San Francisco and Seattle, on the question of Chapters being organized in these respective centers. He further reported that as a result of these conferences a Chapter was being organized in San Francisco.

Canadian Section of A.F.A.

Secretary Hoyt reported that a meeting of the Canadian foundrymen had been held during the week, to consider organization of a Canadian Section of A.F.A.; that a committee had been appointed, and that at a conference with this committee, plans had been layed for organizing such a Section, by the election of Major Anthes as Chairman; Harold J. Roast of Montreal, as Vice Chairman; and John T. Hepburn of Toronto, Secretary-Treasurer.

Secretary Hoyt recommended that the Board authorize financing the Canadian Section on the same basis as provided in the By-Laws for financing Chapters of A.F.A., and on motion duly made and seconded, it was so authorized.

Secretary Hoyt reported that in response to a request, that the Board of Directors had approved by letter ballot local organizations being organized under the name of "Chapter" instead of "Sections" as provided

in the By-Laws, and requested that the Board authorize the use of the term "Chapter" instead of "Section" without requiring that it be referred to the general membership as an amendment. On motion of Director Tour, duly seconded, the use of the term "Chapter" was unanimously approved and authorized.

Molding Sand Research

Director Ballard called attention to the lack of funds for carrying on sand research work, and referred to conditions whereby steel casting producers had to pay a royalty in using materials in this country to foreign organizations.

In replying to Mr. Ballard's statements and request that funds be made available for sand research work, the Secretary read from the minutes of the Board meeting of January 12, 1935, as follows:

> "Following discussion of possible activities of the Foundry Sand Research Committee, the Board voted to approve of special funds being raised, provided Dr. Ries, the Chairman of the Committee, submitted a plan of activities that would require funds and of sufficient importance to justify these being raised.

The Secretary stated that this action had been reported to Dr. Ries and it was hoped that a report would be received at an early date on which could be based a campaign for special funds. No further action was taken.

Election of Officers and Directors

Secretary Hoyt reported that at the annual business meeting held Thursday, October 25, a report of the 1934-35 Nominating Committee had been presented, and that in accordance with the provisions of the By-Laws the Secretary was instructed to cast the unanimous ballot of the members for the following officers and directors:

FOR PRESIDENT, to succeed himself, Dan M. Avey, Editor, "The Foundry," Cleveland.

FOR VICE PRESIDENT, to succeed himself, B. H. Johnson, Assistant to the President, R. D. Wood Company, Philadelphia.

FOR DIRECTORS, to serve three year terms each:

Henry S. Washburn, President, Plainville Casting Co., Plainville, Conn.

Lamar S. Peregoy, President, Sivyer Steel Casting Co., Milwaukee, Wis.

C. E. Davis, Alloy Specialty Co., Coraopolis, Pa.

W. J. Cluff, President, Frederic B. Stevens Inc., Detroit, Mich.

Frank A. Sherman, Vice President and General Manager, Dominion Foundries and Steel, Ltd., Hamilton, Ontario, Canada.

Directors Elect were all present and introduced by the President.

It was announced that the newly elected directors would take the place of the following whose terms of office would then expire: E. H. Ballard, H. Bornstein, S. B. Cuthbert, David Evans, and Franklin G. Smith.

On behalf of the Board, Mr. Lanahan expressed appreciation of the services of the outgoing Directors. This appreciation was responded to

in well chosen words by Director E. H. Ballard, who had served continuously on the Board from 1927 to 1935; three years as a Director; one year as Vice President; one year as President; followed by the three-year term as a Director.

On motion, the final meeting of the 1934-35 Board of Directors stood adjourned.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Minutes of the First Meeting of the 1935-36 Board of Directors

ROYAL YORK HOTEL, TORONTO, AUGUST 23, 1935

This meeting followed the adjournment of the final meeting of the 1934-35 Board, with President Dan M. Avey in the chair, and the following Directors present:

Frank J. Lanahan, Sam Tour, J. L. Wick, Jr., R. F. Harrington, W. L. Seelbach, R. J. Teetor, E. W. Campion, W. J. Cluff, L. S. Peregoy, H. S. Washburn, C. E. Davis, Frank A. Sherman.

Also present: Members of the Advisory Board, E. H. Ballard and A. B. Root, Jr.; Technical Secretary R. E. Kennedy; Secretary C. E. Hoyt.

Organization of New Board

The Board proceeded to organize in accordance with the provisions of the By-Laws. The President named Directors E. W. Campion, H. S. Washburn and Sam Tour as members of the committee to nominate officers and four members of the Executive Committee, as provided for in the By-Laws.

Mr. Campion, for the Committee, submitted the following report:

"Your committee appointed to nominate officers of the Association and members of the Executive Committee submit the following report: First, we recommend that the office of Executive Secretary, Treasurer and Manager of Exhibits be combined, and we so move." Motion duly seconded and approved.

Mr. Campion proceeding, nominated for Executive Secretary, Treasurer and Manager of Exhibits, C. E. Hoyt; for Technical Secretary, R. E. Kennedy; for Assistant Secretary-Treasurer. Jennie Reininga; and moved their election. Motion duly seconded and approved, and the above named officers were duly elected.

Proceeding, Mr. Campion presented the names of Directors E. O. Beardsley, R. J. Teetor, W. L. Seelbach, and James L. Wick, Jr., as members of the Executive Committee, and moved their election. Motion was duly seconded and unanimously approved, whereupon President Avey declared the above duly elected as members of the Executive Committee, to serve with the President, the Vice President and Executive Secretary.

Report of Finance Committee

President Avey called for a report of the Finance Committee on salaries for the year beginning July 1, 1935. Chairman F. J. Lanahan reported as follows:

"Your committee recommends that the salary of the Executive Secretary-Treasurer be \$320.00 per month; salary of the Technical Secretary, \$450.00 per month; salary of Manager of Exhibits, \$320.00 per month; salary of Assistant Secretary-Treasurer, \$220.00 per month; and so move that these salaries be approved." Motion was duly seconded and unanimously approved.

"Your committee further recommends that the President and Executive

Secretary-Treasurer be authorized to employ such office assistants as are necessary for the conduct of Association business, and determine compensations." On motion duly seconded, the recommendation of the Finance Committee was approved.

On motion duly seconded, the bonds of C. E. Hoyt, Executive Secretary-Treasurer, and Jennie Reininga, as Assistant Secretary-Treasurer, were placed at $5,000.00 each, premium to be paid by the Association.

Disbursement of Funds Resolutions

On motion duly seconded and approved, the following resolutions on disbursement of funds were unanimously adopted:

"Resolved that Resolutions required by the Harris Trust and Savings Bank, Chicago, authorizing withdrawal of funds, are hereby approved and the Executive Secretary authorized to certify thereto."

"Resolved that checks for withdrawal of funds deposited in the name of the Association and withdrawal of all securities in the Sinking Fund of the Department of Exhibits of the American Foundrymen's Association held by the Trust Department of the Harris Trust and Savings Bank and the withdrawal of all funds in all interest savings accounts of the Association shall require two signatures as follows:

The President and Executive Secretary-Treasurer,
The Vice President and the Executive Secretary-Treasurer, or
The President and the Vice President."

"Be it further resolved that the Board of Directors authorize an Executive Secretary Expense Account of $500.00, said account to be reconciled at the end of each month by a full statement of expenditures; withdrawal checks to be signed by the Executive Secretary-Treasurer or the Assistant Secretary-Treasurer."

On motion duly seconded, it was voted to continue in effect the resolution adopted at the last annual meeting, authorizing payment of committee meeting expenses, which read as follows:

"Resolved that the Treasurer be authorized to reimburse the traveling expenses of Directors and committee members for attendance at any regularly called Board or Committee meeting with the following exceptions: When meetings are held in conjunction with other committees or associations, the Treasurer is authorized to determine what portion of the expense of attending such meetings shall be paid by the Association."

"No expenses shall be paid to Directors for attendance at meetings held during the week of the Annual Convention of the Association, unless specifically authorized."

It was duly moved, seconded and carried that the President be authorized to make all appointments for standing or special committees not provided for in the By-Laws or by special act of the Board.

Recommendations, Malleable Division Advisory Committee

Technical Secretary Kennedy and Director Teetor reported action taken by the Malleable Division Advisory Committee at its meeting August 21, stating that this Committee was of the opinion that iron made from a white iron base without complete conversion of carbon to graphite should be designated as Pearlitic Malleable, and that the physi-

cal characteristics should be designated by the same method of numbering in vogue in the standard A.S.T.M. Malleable Specifications.

It was moved by Mr. Teetor that the Technical Secretary be instructed to inform all known producers of this class of material of these recommendations and to get their reaction. The motion was seconded and approved.

Molding Sand Researih

It was moved, seconded and carried that the Board reaffirm the authorization of the previous Board for the securing of special funds for Molding Sand Research when and if the Research Committee present a plan of activities justifying such funds being raised.

Bonus for Chapters

Secretary Hoyt recommended that as an aid to financing Chapters of A.F.A., authorization be given to rebate to Chapters not more than $10.00 for new General Firm members, not more than $5.00 for new Limited Firm members and not more than $5.00 for Limited Firm members advanced to the status of General Firm members, whose applications were received through the effort of the local Chapters, with some date being set as the expiration of this rebate offer. It was moved, seconded and carried that the Secretary formulate a resolution and submit it to the Board for approval by letter ballot.

Board of Awards Appropriations

Secretary Hoyt reported that the recommendations made in the Treasurer's report submitted to the Board January 12, 1935, that funds in the interest account of the Award Fund be made available for worthy purposes within the keeping of the articles of agreement of the donors, were presented to the Board of Awards at a meeting on May 11, for their consideration.

He further reported that it was the consensus of opinion of the members of the Board of Awards that before making any appropriations as recommended for prize contests and award other than the annual award, definite plans should be developed and presented for the Board's consideration.

He further reported that the Board of Awards, acting upon the request of the Executive Committee for an appropriation for a special lecture at the annual convention, had adopted the following resolution:

"Resolved that the Board of Awards appropriate from the Board of Awards Interest Fund a sum not to exceed $300.00 to be used at the discretion of the Executive Committee in securing a speaker or speakers at the 1935 Convention, on some subject of general interest to foundrymen."

The Secretary further stated that the Executive Committee decided to take advantage of this opportunity and secure some outstanding speakers for a special meeting on Industrial Health Hazards and Employer Responsibility, and that the expenses of such speakers as had been invited to appear on the program would be defrayed from this fund.

Report on Conference on Industrial Health

President Avey and Secretary Hoyt reported on the informal conference held Thursday afternoon, attended by some twenty-five Board

members and Advisory Board members, to discuss questions prompted by the talks and discussion presented at the special meeting on Health Hazards Wednesday evening.

Mr. Donald E. Cummings of Saranac Laboratories, one of the speakers on Wednesday evening, attended this meeting and spoke at length on what he thought should and could be done, including the making of model studies, formulating standards for foundries of fair and good practice, the importance of correlating procedure in different states and of all helpful information that was available. He placed emphasis on the desirability of Fact Finding.

Director Washburn emphasized the need of some action by A.F.A. offering to all organizations dealing with silicosis problems its services as a clearing house. Director Harrington again emphasized the importance of starting a program of Fact Finding.

It was the unanimous feeling of all present that a program of activities should be carefully considered, and ways for providing funds for support of such activities developed. On motion, the question of developing a program and action was referred to the officers and to the Executive Committee.

Place of 1936 Convention

Secretary Hoyt reported on proposals and agreements for the use of Convention Halls in the cities of Cleveland, Chicago, Detroit, Milwaukee and St. Louis, stating that the conditions of these agreements as to rental rates, charges for services, etc., were comparable.

Following discussion of the advantages of each of the cities named above, it was moved by Director Campion that the 1936 Convention and Exhibit be held in the city of Detroit the week of May 4, and that the officers of the Association be authorized to enter into contractual agreement for the use of Convention Hall for staging exhibits and to make other arrangements. Motion seconded and unanimously carried.

Secretary Hoyt asked for some definite policy in relation to sale of the Cast Metals Handbook, which had just been published and sample copies placed on exhibit at the registration desk during the convention. On motion, this question was referred to the officers who might seek the advice of the Executive Committee.

Mr. Campion moved that the Board officially express appreciation of the work of the Toronto Committee. Motion seconded and carried unanimously.

Mr. Harrington moved that an expression of sympathy and flowers be sent to Vice President Johnson. Motion seconded and unanimously approved.

On motion duly seconded, the following resolution was adopted:

"Resolved that the Executive Committee of this Board be empowered to act for the Board in the interim between Board meetings on all matters requiring Board action."

On motion duly made and seconded, the first meeting of the 1935-1936 Board of Directors stood adjourned to meet again at the call of the President.

Respectfully submitted,

C. E. HOYT, *Executive Secretary.*

Auditor's Report

July 29, 1935.

Mr. Dan M. Avey, President,
American Foundrymen's Association, Inc.,
Chicago, Ill.

Dear Sir:

I have examined the books of the American Foundrymen's Association, Inc., for the year ending June 30, 1935 and submit herewith the following statements:

Exhibit A—Balance Sheet, June 30, 1935
Exhibit B—Income and Expenses for the Year
Exhibit C—Surplus, June 30, 1935
Schedule I—Award Funds, June 30, 1935
Schedule II—Reserve Fund, June 30, 1935
Schedule III—Cash Receipts and Disbursements

The securities in the Reserve Fund as shown by the Balance Sheet are stated at cost. The market value thereof is $1,054.05 less than cost.

There was an excess of Income over Expenses for the year of $376.30, to which should be added the amount appropriated out of the Reserve Fund, $1,350, making a total addition to the Surplus of the year of $1,726.30. Part of the expenses applicable to the Exhibit and Convention held in October 1934 were paid in the previous year.

Subject to these remarks, it is my opinion that the Balance Sheet as at June 30, 1935, shown in Exhibit A attached, correctly reflects the condition of the Association at that date and as shown by the books.

Respectfully submitted,

Robert T. Pritchard,
Certified Public Accountant.

Note: A copy of the Auditor's Balance Sheet and Statement of Cash Receipts and Disbursements is shown in the following pages.

BALANCE SHEET AS AT JUNE 30, 1935

ASSETS

	June 30, 1935
ASSOCIATION ASSETS	
Cash in Bank, Schedule III	$ 909.51
Accounts Receivable for dues, etc.	496.90
Supplies on Hand	950.60
Furniture and Fixtures, less Depreciation Reserve	285.70
	$ 2,642.71
RESERVE FUND (Schedule II)	
Investments (Market Value, $20,651.50)	$21,705.55
Cash in Bank on Savings Account	32.34
	$21,737.89
STEEL CASTINGS TEST FUND	
Cash in Bank on Savings Account	$ 312.58
Total	$24,693.18

LIABILITIES

	June 30, 1935
ASSOCIATION LIABILITIES	
Unpaid Bills	$ 726.44
Dues Paid in Advance	1,161.75
Unexpended Appropriations for Sand Research	250.35
Unexpended Appropriations for Steel Castings Research	1,450.00
Total Association Liabilities	3,588.54
Surplus (Deficit)	945.83
	$ 2,642.71
RESERVE FUND (Schedule II)	
Principal of the Fund	$21,737.89
	$21,737.89
STEEL CASTINGS TEST FUND	
Unexpended	$ 312.58
Total	$24,693.18

CASH RECEIPTS AND DISBURSEMENTS

For the Year Ending June 30, 1935

CASH IN BANK, July 1, 1934		$ 1,005.28
RECEIPTS		
Dues—1933-34	$ 139.75	
1934-35	17,353.83	
1935-36	1,161.75	
Subscriptions and Sales of Publications	2,492.99	
Exhibit		
Permits	2,650.00	
Space Rentals	21,694.25	
Banquet Tickets, etc., at Convention	1,660.70	
Registration Fees at Convention	2,251.50	
Reimbursed by Awards Fund	11.63	
Rental Received 1933 Exhibit	40.00	
Appropriated from Reserve Fund	1,350.00	
Total Receipts		50,806.40
		$51,811.68
DISBURSEMENTS		
Salaries and Clerical Expense	$21,365.01	
Committee Traveling Expense	1,774.68	
Publications	7,435.23	
Printing	2,302.15	
Postage	1,878.63	
Office Rent	2,625.00	
Telephone and Telegraph	465.00	
Office Expense	509.95	
Exchange	62.40	
General Expense	79.17	
Taxes	19.36	
Traveling Expense	1,471.01	
Insurance (Public Liability—Exhibit)	243.00	
Rental of Building and Expense for Exhibit	2,517.38	
Exhibit Installation	725.82	
Advertising and Promotion—Exhibit	2,134.41	
Dues—Other Associations	73.50	
Audit	87.50	
Convention Expense	3,084.50	
Registration Expense	268.55	
Chapter Expense	656.31	
Sand Research	123.61	
Note Due to Bank	1,000.00	
Total Disbursements		50,902.17
CASH IN BANK, June 30, 1935		$ 909.51

Recommended Practice for Sand Cast Aluminum Alloys

Report of Non-Ferrous Division Committee on Recommended Practices

Preface

In preparing these recommendations the Non-Ferrous Division of the American Foundrymen's Association, through its Recommended Practice Committee, has attempted to collect, through reliable sources, such information as will be of practical use to foundrymen handling nonferrous alloys. These present recommendations are the first of a contemplated series on various groups of nonferrous alloys.

Although the various practices which are treated are recommended by those considered specialists in the various fields, these practices are not intended as specifications. The alloy numbers have no particular significance other than to differentiate alloys in this particular publication. Wherever possible these numbers are identified with existing alloy specifications.

The publishing of data relative to various alloys and treatment of such alloys by the American Foundrymen's Association, does not insure anyone using such data against liability for infringement of any patents that may now exist or are pending. It should also be understood that the publication of data concerning patented alloys or processes does not constitute a recommendation of any patent or proprietary rights that are involved.

This first report is limited to aluminum alloys and is divided as follows:

A. *General Recommendations*
   1. *Molding—(a) Sands, (b) Facing, (c) Gating and heading, and (d) Cores.*
   2. *Melting and pouring—(a) Types of melting equipment, (b) Precautions, (c) Fluxing and Deoxidizing, and (d) Melting and Pouring Ranges.*
   3. *Finishing.*
   4. *Heat Treatment.*
   5. *Defects, Their Cause and Prevention.*

B. *Recommended Practices for the Common Al-Cu alloys.*

C. *Recommended Practices for the Heat Treated Al-Cu alloys.*

D. *Recommended Practices for the Common Al-Si alloys.*

E. *Recommended Practices for the Heat Treated Al-Si alloys.*

F. Recommended Practices for the Al-Mg alloys.

Sections B to F inclusive are each divided in sections, as follows:

1. *Chemical Control Limits.*
2. *Physical Properties of Castings.*
3. *Conforming Specifications.*
4. *Development.*
5. *Fields of Use.*

Nonferrous Division Committee on Recommended Practices

T. D. STAY, CHAIRMAN	E. F. HESS
W. M. BALL, JR.	H. W. MAACK
A. L. BOEGEHOLD	R. W. PARSONS
L. H. FAWCETT	T. C. WATTS
H. B. GARDNER	

A. GENERAL RECOMMENDATIONS FOR ALUMINUM ALLOYS

1. *Molding*

(a) Very satisfactory molding sands for the aluminum alloys described herein fall within the A.F.A. 1G or 2G classification.[1] A sand of this type is fine enough to impart a smooth surface to the castings without being too "close" to prevent the steam and core gases from escaping.

A good molding sand for aluminum alloys will generally meet the following specifications:

Compressive Strength, lbs. per sq. in.	5-9
Permeability (A.F.A. Standards)	4-8
Clay Content—Per Cent	20-35
Fineness Number	175-250

Coarser sand with less clay bond can be used. This will depend largely upon the type of castings made, flexibility of sand handling methods, and supply of sand available.

(b) *Facing:* It is not common practice to use a facing sand for aluminum alloy castings except in special cases. If the molding sand used will meet the above specifications, it will be fine enough to impart a satisfactory smoothness to the casting.

(c) *Gating and Heading:* Because many aluminum alloys are "hot short" at temperatures slightly below their freezing points and have a high solidification shrinkage, there is a tendency for draws, shrinks, and cracks to occur unless the mold is properly gated.

The strength of castings is dependent to a great extent upon

[1] Testing and Grading Foundry Sands, Standards and Tentative Standards, 1931, American Foundrymen's Association, pp. 132-135.

the proper proportion and location of gates. It is frequently possible to increase the strength of improperly gated castings as determined by actual breakdown tests, by as much as 50 to 100 per cent through the redesign or relocation of the gates.

As a rule, castings should be gated in such a manner as to promote progressive feeding so that the sections farthest from the gates should be the first to solidify. When a light section adjoins a heavy section, the gate should usually enter the lighter section. In many instances, in order to equalize the rate of solidification in heavy and light sections, it is necessary to place a riser on the heavy section to feed it, and increase its rate of solidification by the proper use of chills.

Multiple gating is recommended, that is, the metal should enter the casting through a number of gates instead of one or a few as is customary in iron practice. The use of multiple gates will permit pouring at a lower temperature by minimizing local overheating of the sand, and will insure a rapid and even rate of solidification in all parts of the casting.

Gates should be placed so that the metal will enter the mold cavity with a minimum of agitation to prevent the formation of oxide and dross. It is advisable to employ skim gates as much as possible.

When determining the location of risers, the molder should consider ease in cleaning and trimming. For this reason, the position of risers should be such that their removal may be affected with the minimum of time and trouble.

Risers must be of sufficient size so that they will remain molten until the casting has completely solidified, acting both as reservoirs and pressure heads. They should also be cut into the mold in such a manner that they will function satisfactorily and, at the same time, be easy to remove during the trimming operations.

The aluminum-copper alloys containing approximately 4 per cent copper are the most susceptible to "hot short" cracks. Added precautions must be observed in the foundry practice for these alloys to prevent as much as possible any resistance of the mold to contraction. The placing of gates, sprues and risers, both with respect to the casting and flask bars, the ramming of the sand and strength of cores, as well as the placing of chills, must be carefully considered when handling these alloys. The aluminum-silicon alloys, both common and heat treated, are practically free from

"hot shortness", a property which is often utilized in making intricate castings.

The alloys containing magnesium tend to dross when subjected to agitation.

This tendency toward dross formation varies with magnesium content, being somewhat less in the heat treated aluminum-silicon alloys than in the aluminum-magnesium alloys. It is therefore necessary to gate and pour in such a way as to exclude dross from the casting. In the case of both types of alloys, it is advisable to use special skimming devices to accomplish this.

(d) *Cores:* Cores for aluminum alloy castings should be made as soft as is consistent with safe handling. Because of the "hot short" condition of some of the alloys at temperatures just below the solidification point, it is important that the cores offer a minimum resistance to the contraction of the cooling metal. This of course applies to a lesser degree to the aluminum-silicon alloys than the aluminum-copper alloys.

A suitable core sand consists of a mixture of silica sand and sometimes molding sand, held together by an added artificial bonding material. The usual bonding materials are made chiefly from linseed and other oils, rosin, dextrin, pitch, flour, or combinations of these materials. The selection of the proper binder and the core mixture is dependent upon the use to which the core is put. The properties of cores may be regulated by varying the percentage as well as the kind of binder used.

2. Melting and Pouring

(a) *Types of Melting Equipment:* Aluminum alloys are most commonly remelted for foundry use in individually fired pot furnaces, either of the stationary or tilting types. These may be fired with gas, fuel oil, coke, or electricity, although gas or fuel oil are generally used because of convenience and economy, and also because their use permits close control of furnace temperature Such furnaces are preferably fired indirectly, care being taken to prevent the products of combustion from contacting the molten metal. Melting by a direct flame as in reverberatory type furnaces or in crucible type furnaces where the flame impinges on the metal, is not a preferred practice because of the possibility of absorbing gases which may later cause pinhole porosity. This tendency increases with increase in melting temperature. A crucible cover is

recommended when the latter type furnace is used for aluminum alloys.

Cast iron melting pots are often used with the above furnaces and prove very satisfactory providing that suitable care is taken to prevent excessive iron pickup during the melting operation. They should be carefully cleaned at the end of each day, and then given a suitable coating to act as a protection against the action of the molten metal. A whiting wash has been used with good results in many foundries.

Non-metallic melting pots such as graphite or carborundum are often preferable to iron melting pots for some of the alloys. This is particularly true of the aluminum-silicon alloys to be heat treated and the aluminum-magnesium alloys because of the detrimental effect of iron upon mechanical properties and corrosion resistance. Ordinary plumbago crucibles can also be used satisfactorily without absorbing an appreciable amount of silicon from the crucible.

(b) *Precautions:* An important consideration is the temperature of melting and pouring. The metal should be poured at the lowest possible temperature at which the casting will not misrun and still allow air bubbles and dross to escape from the metal before it solidifies. However, it is not sufficient that only the pouring temperature be low. The melting and holding temperatures should be kept at a minimum to prevent the formation of oxide and absorption of furnace gases. Alloys which have been overheated will show a coarser, more open grain structure than those which have been properly melted, even though they are cooled to the proper temperature before pouring. Similar results are observed if the alloys are held in the molten state for a long time before they are poured; the higher the holding temperature, the shorter the time required to produce inferior results. If the metal has been injured by overheating, the harmful effects may be at least partially corrected by allowing it to solidify and remelting under proper temperature control.

Accurate control of metal temperatures from the melting furnace to the pouring ladle is an essential part of foundry technique. Thermocouples protected by a suitably coated cast iron tube are recommended for controlling the temperature in the melting furnaces. For rapid and accurate temperature determination immediately before pouring, an open end chromel-alumel thermocouple made from No. 8 gage asbestos covered wire and

connected by proper lead wires to an indicating pyrometer will give satisfactory results. Such a couple should be agitated slightly while in the metal to prevent the metal bridging the leads at the surface.

(c) *Fluxing and Deoxidizing:* With satisfactory melting practice, it is not necessary to use a flux to obtain good castings. However, fluxing is sometimes beneficial, particularly when considerable foundry scrap or secondary metal is included in the melt as often customary in the case of the common aluminum-copper alloys. For this purpose such fluxes as active or inert gases, volatile chlorides and fluorides, or stable metallic salts are generally used. Of these, zinc chloride, aluminum chloride, a mixture of one or more chlorides and fluorides or cryolite, and chlorine gas are in most common use. Fluxes composed of one or more alkaline earth metal salts find particular application with the aluminum-magnesium alloys. A number of these appear on the market under various trade names although it is suggested that recommendations as to the type of flux be obtained from the manufacturer of the alloy with which the flux is to be used.

The operation of fluxing must, however, be carefully and properly carried out if any benefits are to be realized. When solid fluxes are employed, they must be absolutely dry and used in such a manner that the maximum amount of molten metal is acted upon. Gaseous fluxes are generally piped to the bottom of the melting pot and allowed to bubble through the metal.

(d) *Melting and Pouring Range:* If the metal is alloyed in the foundry, the aluminum is first melted, and at approximately 1300° F. to 1350° F. the necessary alloying elements are added in the form of commercially pure metals or rich alloys with aluminum. Iron should be added at temperatures above 1400° F. to effect solution.

The order of adding the alloying elements is usually copper, silicon, iron, manganese, nickel, and magnesium. The alloying additions should be made gradually and in pieces of such shape and size that the molten aluminum will not freeze and rapid solution will take place. The metal should be thoroughly stirred after the alloying elements are in solution.

It is possible to obtain most of the final casting *alloys* in ingot form made up to the required chemical composition. This is perhaps the most simple method for the melting room since it is only

necessary to remelt such ingot, thereby eliminating irregularities in alloying practice and violent stirring prior to pouring.

If a certain percentage of foundry scrap is used in the melt, this material should be charged first to provide a heel of molten metal for the aluminum or alloy ingot. This procedure will shorten the melting time because pure aluminum by itself melts at a somewhat higher temperature and may often be in the form of large pigs or ingots which will also retard melting. The latter also applies to alloy ingot.

The maximum melting temperature of aluminum alloys should be no higher than necessary to satisfactorily pour the castings. It is possible to pour some castings at 1200° F. but most of them are generally poured between 1250 and 1500 degrees Fahr.

3. Finishing

Gates and risers are usually removed from the castings by means of a band saw of suitable tooth design and operated at speeds of from 2,000 to 5,000 or more feet per minute. In some instances, it is necessary to remove risers by means of pneumatic chisels.

The final finishing of castings is generally performed by grinding wheels, disk grinders, and files. Sand blasting is also employed both as a means of cleaning and as a final finish, particularly for architectural castings. The degree of finish is largely determined by the use to which the casting is put.

Welding by approved methods may be done with the oxy-acetylene torch or electric arc. Welding of other than slight surface defects such as sand holes and misruns is not recommended. Castings should preferably be preheated before welding to minimize the danger of cracking. They should likewise be cooled slowly to room temperature after welding. The aluminum-silicon alloys are relatively easy to weld, being practically free from the tendency to crack except when the casting is very intricate or extreme variations in section thickness exist. The aluminum-copper alloys are susceptible to cracking when welded owing to "hot shortness". The aluminum-magnesium alloys are extremely difficult to weld satisfactorily because of dross formed by oxidation of the molten alloy.

Aluminum alloy castings lend themselves to practically all methods of ornamental finishing. Such mechanical finishes as produced by polishing, buffing, or satin finishing are readily ap-

plied with polishing equipment of the same type as used with other metals. Abrasive wheels made up of sewed muslin buffs 6 to 12 inches in diameter, to which emery of the desired size is glued are generally employed, operating at speeds of 3400 to 4400 R.P.M. For higher polishes, muslin or felt wheels and a polishing material such as tripoli or greaseless compounds, may be used. Other desirable finishes or combinations of finishes may be applied with circular wire or fiber brushes or hand rubbing.

For certain applications, electroplated finishes are desired. Such plated finishes as nickel, copper, zinc, and chromium are as easily applied to aluminum alloys as to the other metals, providing certain simple precautions are observed. Care should be taken to select the type of alloy and plate best suited to the particular job. Generally speaking, electroplated coatings find their best possibilities for parts not subject to continuous out-door exposure.

The electrolytic process of oxidation or anodic treatment is often used as a means of finishing certain aluminum alloy castings. Several methods for producing such electrochemical coatings are in use, being differentiated by the electrolyte used. Otherwise, the processes are quite similar, in that the article to be coated is made the anode in a bath of specified composition. The oxide coatings so produced possess in addition to their protective value, remarkable abrasion resistance, dielectric characteristics and electrical insulating properties. Certain types of coatings are very absorbent and can be readily impregnated by dyes and mineral pigments both for color effects and to increase the corrosion resisting properties.

4. Heat Treatment[2]

The mechanical properties of many aluminum alloys may be materially improved by a suitable heat treatment. The type of heat treatment employed is determined in most cases by the properties desired in the castings.

Alloys given a solution treatment possess the highest ductility and impact resistance. This treatment consists of heating the casting to a known temperature, holding at that temperature for the correct length of time, and then quenching. The object of this treatment is to bring the soluble constituents of the alloys into solid solution, and to retain this solid solution in a supersaturated

[2] Many of the heat treatment processes for aluminum alloys are covered by a number of existing U. S. Patents, including Nos. 1,508,556, 1,572,488, 1,394,534, and 1,572,487.

condition by rapid cooling. A heat treatment of this type is desirable when maximum shock resisting properties combined with high strength are required.

A precipitation treatment following the solution treatment results in a material increase in the yield strength, tensile strength, and hardness of the alloy at some sacrifice of ductility. This treatment is carried out at a relatively low temperature for a predetermined length of time. Maximum strength and hardness are obtained by prolonging the precipitation treatment.

Certain alloys are also subject to improvements in strength and hardness through a precipitation treatment only. Such a treatment, either by itself or in connection with a solution treatment, and with proper selection of time and temperature relations, is also used to minimize the tendency for castings to "grow" when they are subsequently placed in service at elevated temperatures. A precipitation treatment alone is often used in the case of very intricate castings to avoid possible quenching stresses which might be introduced if a solution treatment were used, and providing that the resulting properties in the casting are satisfactory. Such treatments usually increase yield strength, tensile strength, and hardness, but do not improve elongation.

5. *Defects, Their Causes and Prevention*

The principal defects in aluminum alloy castings other than those resulting from improperly tempered sand, are those due to poor molding or core room practice and dross and inclusions, shrinkage, porosity, and cracks. Such defects are largely a function of melting, pouring, and gating practice and their elimination must come through improvement or change in some or all of these factors.

Dross and blow holes are usually caused by improper pouring and gating which permits too great an agitation of the metal as it is poured and as it enters the mold cavity. Too much dirty scrap in the melt and improper skimming of the metal, both in the melting furnace and pouring ladle, are responsible for much dross being carried into the castings.

The presence of shrinkage cavities in certain parts of the casting indicates lack of feeding or perhaps a too slow rate of solidification. This type of shrinkage can usually be eliminated by the use of adequate risers; by a suitable combination of chills

and risers; by a change of gating such as to supply cooler metal to the areas in which the shrinkage has occurred.

Surface shrinkage when accompanied by relative large grain size is generally an indication of a high pouring temperature. By increasing the number of gates it may be possible to pour the casting at a lower temperature, thus decreasing the amount of hot metal at any one point and overcoming the tendency for shrinkage to occur. High pouring temperature is not, however, the only cause of surface shrinkage. It is sometimes caused by hard ramming, which lowers the permeability of the mold. Surface shrinkage on cored castings sometimes indicates a core shift or sag resulting in uneven wall thickness, which in turn affects the rate of solidification. Thin castings will often show surface shrinkage at the gates; this may be eliminated by a small riser in the runner outside of the gate.

The question of pinhole porosity, in the form of tiny cavities often uncovered when castings are machined, continues to puzzle foundrymen. Its origin is not clearly defined but it usually is the result of a combination of a number of factors. For this reason there are listed below the principal factors which influence the occurrence of pinhole porosity.

1. High melting and pouring temperatures—absorption of gas in melting.
2. High percentage of scrap—unknown origin or composition and not clean.
3. Insufficient feeding.
4. Rate of solidification too slow.
5. Sand too wet or rammed too tight.
6. Composition of alloy—porosity will vary with types of alloys.

Cracking in castings is the result of "hot shortness" in the alloy at temperatures just below the freezing point. There are two general methods in use to minimize cracking. The first of these is to eliminate as much as possible, potential sources of resistance to contraction as the casting cools through the hot short range. The second is to strengthen these weak parts of the casting by the use of ribs, fillets, or fins. Gating technique which has for its purpose the production of the soundest possible castings will often prevent cracking which would occur when the principal thought is only to get the liquid metal into the mold cavity.

B. RECOMMENDED PRACTICE FOR THE COMMON ALUMINUM-COPPER ALLOYS

1. *Chemical Control Limits*

Alloy	Cu. Per cent	Iron Per cent	Si. Per cent	Zn. Per cent	Other Elements
B-11	7.0-8.5	—	—	0.2 Max.	Total impurities less than 1.5%
B-12	7.0-8.5	0.8-1.2	1.0-1.5	0.2 Max.	Total impurities less than 0.3%
B-13	6.0-8.0	1.0-1.5	*	1.0-2.5	**
B-14	11.0-13.5	—	—	—	

* The use of higher silicon content up to about 2.0% improves the casting qualities of this alloy without any adverse effect on the physical properties or machining characteristics of the casting. This is recognized in the following specifications.

S.A.E. 33—2.0% Max.

A.S.T.M. B26-33T Alloy C—1.0-3.0%.

** A.S.T.M. B26-33T Alloy C—Magnesium 0.05% Max., Manganese 0.3% Max., and other elements 1.0% Max.

The strength of the aluminum-copper sand castings increases rapidly with copper content up to about 4 per cent and then more slowly up to about 12 per cent. Conversely, the elongation decreases continuously and the alloys become quite brittle at 10 per cent copper or above. The most favorable combination of strength, elongation, toughness, and casting properties seems to be reached at about 7 to 8 per cent copper.

The addition of controlled amounts of silicon and iron as in alloy B-12, effects a distinct improvement in the casting characteristics of these alloys. Iron tends to reduce the "hot shortness" of the alloy, thereby preventing to a considerable extent the occurrence of cracks. Silicon promotes fluidity of the alloy, making it easier to cast.

Another modification of the original 8 per cent (B-11) alloy consists in the addition of small amounts of zinc for the purpose of improving machinability. At the same time, it is possible to increase the iron content over that of alloy B-11. This alloy containing zinc is alloy B-13.

Alloy B-14 containing approximately 12 per cent copper and therefore rather brittle, has been found especially suited for castings requiring pressure tightness but which are lightly stressed and not subjected to impact shocks.

2. *Physical Properties of Sand Castings*

	Alloy B-11	Alloy B-12	Alloy B-13	Alloy B-14
Ultimate Tensile Strength, Lb. per sq. in. Min. to Avg.)[1]	19000–22000	19000–22000	19000–23000	21000–24000
Yield Strength, Lb. per sq. in. Permanent Set=0.2% (Avg.)	14000	14000	14000	14000
Modulus of Elasticity, Lb. per sq. in x 10^6 (Approx.)	10	10	10	10
Elongation, % in 2 in. (Min. to Avg.)[2]	1.5–2.0	1.0–2.0	1.0–2.0	1.0–2.0
Brinell Hardness, 10 mm. ball—500 Kg. load (Approx.)	65	60	70	75
Ultimate Compressive Strength, Lb. per sq. in. (Approx.)[3]	38000	38000	44000	45000
Specific Gravity (Approx.)	2.83	2.84	2.86	2.89
Weight per cu. in. (Lbs.) (Approx.)	0.103	0.103	0.104	0.104
Pattern Maker's Shrinkage—inches per foot	1/10–5/32	1/10–5/32	1/10–5/32	1/10–5/32
Solidification Range—°F. (Approx.)	1175–1004	1175–1004	1175–1004	1160–1004
Electrical Conductivity (Percent. of annealed copper standard at 20°C.) (Approx.)	35	32	30	39
Endurance Limit, Lb. per sq. in. (R. R. Moore Machine 500,000,000 Reversals)	7500	7500	8500	10000
Coefficient of Thermal Expansion (Per °F. x 10^{-6}) (68–212°F.)	12.5	12.2	12.2	12.2
Coefficient of Thermal Expansion (Per °F. x 10^{-6}) (68–572°F.)	13.6	13.3	13.3	13.3

[1] Tension values determined from standard A.S.T.M. ½ in. diameter separately cast test specimens.

[2] Usually not included in commercial specifications because of the difficulty of measuring small elongations with accuracy.

[3] Results of tests on specimens having 1/r ratio of 20. All specimens failed by lateral bending.

3. *Conforming Specifications*

Alloy		
B-11	Aluminum Company of America	No. 12 Alloy
	Society of Automotive Engineers	No. 30 Alloy
	U. S. Army Ordnance Department	57-72 Grade 5
B-12	Aluminum Company of America	No. 212 Alloy
	Society of Automotive Engineers	No. 36 Alloy
	American Society for Testing Materials	No. B26-33T Alloy B
B-13	Aluminum Company of America	No. 112 Alloy
	Society of Automotive Engineers	No. 33 Alloy
	American Society for Testing Materials	No. B26-33T Alloy C
	U. S. Army Ordnance Department	57-72 Grade 7
B-14	Aluminum Company of America	No. 109 Alloy
	Society of Automotive Engineers	No. 32 Alloy
	American Society for Testing Materials	No. B26-33T Alloy E

4. *Development*

The aluminum casting industry in America originally developed around alloys in which copper was the principal hardening ingredient. The most widely used of these alloys, commonly known as No. 12 alloy, was made by the addition of approximately 8 per cent copper to commercial aluminum ingot.

For a long time, alloy B-11, commonly known as No. 12 alloy, was the standard casting alloy but in recent years it has been replaced largely by other alloys having better foundry characteristics. While alloy B-11 is a fair casting alloy for general purposes, other alloys were developed to meet the more exacting requirements of the trade. Variations from the original chemical composition have created a group of alloys known as the common aluminum-copper alloys.

These alloys are easy to cast providing that the pattern is not too intricate. They are somewhat "hot short" and therefore susceptible to cracking under certain conditions. They are reasonably hard and machine well. The corrosion resistance of this group of alloys, because of the high copper content, is not nearly so good as that of the aluminum-silicon alloys and aluminum-magnesium alloys or heat treated alloys containing copper in lower percentages.

5. *Field of Use*

The common aluminum-copper alloys are still used quite extensively for castings which do not require exceptionally high mechanical properties or resistance to impact. They are employed in the automotive industry for crankcases, oil pans, transmission housings, manifolds, carburetors, and miscellaneous fittings and parts for body, chassis, and engine.

In addition, the alloys are used in casting various parts of washing machines, and as die castings for vacuum cleaners, multigraphs, typewriters, and adding machines. It has been estimated that 50 per cent of the aluminum foundry output of castings is made in the common aluminum-copper alloys.

The majority of such castings are made in the 8 per cent copper-2 per cent zinc alloy (B13 alloy). A much smaller number of the castings are made in the remaining three alloys. The original 8 per cent copper (B-11) alloy is still used extensively for patterns, matchboard, and core box equipment. Alloy B-14 is well suited for pressure tight castings such as automotive manifolds, pump housing, and carburetors, which are lightly stressed and not subjected to impact shocks.

C. RECOMMENDED PRACTICE FOR THE HEAT TREATED ALUMINUM-COPPER ALLOYS[1]

1. *Chemical Control Limits.*

Alloy	Cu. Percent	Iron Percent	Si. Percent	Zn. Percent	Mn. Percent	Mg. Percent	Ni. Percent	Others
B-21 HT1	4.0-5.0	1.0 max.	1.2 max.	0.25 max.*	0.25 max.**	0.02	...	Total elements other than Cu-Al 2.5% max.
B-21 HT2	"	"	"	"	"	0.02	...	
B-21 HT3	"	"	"	"	"	0.02†	...	
B-22 HT1	3.75-4.50	0.75 max.	0.50 max.	...	...	1.25-1.75	1.75-2.25	Total others 0.25% max.
B-22 HT2	"	"	"	...	...	"	"	
B-23 HT1	9.25-10.75	0.90-1.5	...	...	...	0.15-0.35	...	Total others 0.75% max.
B-23 HT2	"	"	...	...	...	"	...	

*U. S. Navy Dept. 46A1c class 4—zinc 0.03% max.
**U. S. Navy Dept. 46A1c class 4—manganese 0.03% max.
†A. S. T. M. B26-33T Grade GG—magnesium 0.3% max.

The improvement in the mechanical properties of this group of alloys by heat treatment is possible largely because of the composition which must be closely controlled between the limits specified above. The best combination of strength and ductility is obtained by a solution heat treatment followed by quenching (See Section A4). Tensile strength and hardness may then be further increased at a sacrifice of ductility by a precipitation treatment.

The presence of magnesium results in an additional increase in tensile strength and hardness and reduction of ductility by the precipitation heat treatment. Additions of magnesium up to 0.3 per cent are beneficial when maximum strength and hardness are desired and ductility is not necessary.

Nickel is added to alloy B-23 to improve the strength at elevated temperatures and to minimize growth in the castings.

Excess iron content in all of the alloys adversely affects machinability and tends to give a coarse and porous crystal structure.

Silicon in small amounts increases soundness but in larger amounts affects machinability and prevents in some cases, complete and satisfactory heat treatment.

[1] U. S. Patents 1,572,487; 1,394,534; 1,732,557; 1,732,573 and 1,822,877.

2. *Physical Properties of Sand Castings.*

	Alloy B-21 HT1	Alloy B-21 HT2	Alloy B-21 HT3	Alloy B-22 HT1	Alloy B-22 HT2	Alloy B-23 HT1	Alloy B-23 HT2
Ultimate Tensile Strength, Lb. per sq. in. (Min. to Avg.)[1]	29000-32000	32000-35000	36000-40000	29000-32000	32000-36000	23000-25000	30000-35000
Yield Strength, Lb. per sq. in. (Permanent Set=0.2%) (Avg.)	16000	22000	27000	24000	30000	21000	30000
Modulus of Elasticity, Lb. per sq. in. X 10^6 (Approx.)	10	10	10	10	10	10	10
Elongation, Per cent in 2 in. (Min. to Avg.)	6.0-9.0	3.0-5.0	0.0-1.0	0.0	0.0	0.5-1.0	0.0
Brinell Hardness, 10 mm ball—500 Kg load (Approx.)	65	80	95	95	100	75	110
Ultimate Compressive Strength, Lb. per sq. in. (Approx.)[2]	43000	48000	56000	.....	70000	54000	80000
Specific Gravity (Approx.)	2.77	2.77	2.77	2.79	2.79	2.93	2.93
Weight per cu. in—Lbs. (Approx.)	0.10	0.10	0.10	0.101	0.101	0.106	0.106
Pattern Maker's Shrinkage, inches per foot	1/10-5/32	1/10-5/32	1/10-5/32	1/10-5/32	1/10-5/32	1/10-5/32	1/10-5/32
Solidification Range—°F (Approx.)	1195-1020	1195-1020	1195-1020	1165-995	1165-995	1160-1004	1160-1004
Electrical Conductivity (Percent of annealed copper standard at 20°C) (Approx.)	35	....	....	36	....	40	37
Endurance Limit, Lb. per sq. in. (R. R. Moore Machine 500,000,000 reversals)	6000	6500	7000	....	8000	9500	....
Coefficient of Thermal Expansion (Per °F X 10^{-6}) 68-212°F	12.7	12.7	12.7	12.5	12.5	12.2	12.2
68-572°F	13.8	13.8	13.8	13.6	13.6	13.0	13.0

[1]Tension values determined from standard ½ in. diameter A.S.T.M. separately cast specimens
[2]Results of tests on specimens having 1/r ratio of 20. All specimens failed by lateral bending

3. *Conforming Specifications.*

B-21 HT1	Aluminum Company of America.........	No. 195-T4 Alloy
	Society of Automotive Engineers........	No. 38 Alloy
	American Society for Testing Materials..	No. B26-33T Alloy G HTT1
	U. S. Army Ordnance Department.......	No. 57-72-2
	U. S. Navy Department.................	No. 46A1c Class 4
B-21 HT2	Aluminum Company of America........	No. 195-T6 Alloy
	American Society for Testing Materials..	No. B26-33T Alloy G HTT2
	U. S. Army Ordnance Department.......	No. 57-72-5
B-21 HT3	Aluminum Company of America.........	No. 195-T62 Alloy
	American Society for Testing Materials..	No. B26-33T Alloy G HTT3
	American Society for Testing Materials..	No. B-26-33T Alloy GG
B-22 HT1	Aluminum Company of America.........	No. 142-T571 Alloy
B-22 HT2	Aluminum Company of America.........	No. 142-T61 Alloy
	Society of Automotive Engineers........	No. 39 Alloy
	U. S. Army Ordnance Department.......	No. 57-72-1B Alloy A
	American Society for Testing Materials..	No. B26-33T Alloy H
B-23 HT1	Aluminum Company of America.........	No. 122-T2 Alloy
	U. S. Army Ordnance Department........	57-72 Grade 6
B-23 HT2	Aluminum Company of America.........	No. 122-T61 Alloy
	Society of Automotive Engineers........	No. 34 Alloy
	American Society for Testing Materials..	No. B26-33T Alloy F

4. *Development.*

The heat treated aluminum-copper alloys were developed to meet the demands of industry for greater strength, ductility, and impact resistance in castings than possible in the common aluminum-copper alloys. The first of the group to be developed was alloy B-21, containing 4 to 5 per cent copper. This has found wide application as a general engineering alloy. Following this, alloys B-22 and B-23 were developed for more specific applications, particularly for pistons and cylinder heads in the aircraft and automotive fields.

The heat treated aluminum-copper alloys are somewhat more difficult to cast than the common aluminum-copper alloys because of certain differences in casting characteristics. The alloys in general possess good hardness and machine well. The corrosion resistance of the alloys, while not so good as that of the aluminum-silicon alloys, is superior to that of the common aluminum-copper alloys.

Alloy B-21 has the best combination of strength, ductility, and resistance to impact. It is somewhat "hot short" and special attention must be given to foundry technique to overcome this tendency. The alloy is not particularly adapted to intricate thin walled castings which must be leak proof.

Alloys B-22 and B-23, developed principally for pistons and cylinder heads, possess high tensile strength, hardness, and resistance to wear at normal temperatures and good strength at elevated temperatures.

5. *Field of Use.*

Alloy B-21 with its various combinations of mechanical properties possible by heat treatment is widely used as a general engineering material. It is used for crankcases for trucks, motor coaches, and aircraft engines. It is also used for miscellaneous fittings for marine, automotive, outboard motor, and aircraft applications. In addition to this, there are many applications of this alloy in the electrical, machine tool, textile, and other industries.

As previously stated, alloys B-22 and B-23 are largely used for aircraft, automotive, and marine pistons although they are being displaced to a certain extent by a recently developed aluminum-silicon heat treated alloy. They are also used for cylinder heads on some aircraft engines, thereby utilizing the property of good strength at temperatures of 500 to 600 degrees Fahr.

D. RECOMMENDED PRACTICE FOR THE COMMON ALUMINUM-SILICON ALLOYS

1. *Chemical Control Limits.*

Alloy	Per Cent Cu.	Per Cent Iron	Per Cent Si.	Per Cent Zn.	Per Cent Mn.	Per Cent Mg.	Per Cent Other Elements
B-31*	.10 max.[1]	0.80 max.	4.5- 6.0	.03 max.[2]	0.03 max.	0.03 max.	0.03 max. each
B-32	.15 max.[3]	0.80 max.	12.0-13.0	.03 max.[4]	.25 max.[5]	0.03 max.	—

*Conforms to U. S. Navy Dept. Specification 46A1c class 2.

[1] A.S.T.M. No. 26-33T Alloy J—0.40% copper max.

[2] A.S.T.M. No 26-33T Alloy J—0.20% zinc max.

[3] A.S.T.M. No 26-33T Alloy K—0.30% copper max.

[4] A.S.T.M. No. 26-33T Alloy K—0.20% zinc max.

[5] A.S.T.M. No. 26-33T Alloy K—0.50% manganese max.

The presence of the various impurities has an appreciable effect upon the mechanical properties and corrosion resistance of alloy B-31. The corrosion resistance is lowered by the presence of copper and zinc and to a lesser extent by iron. The per cent of elongation is lowered by the presence of iron and to a lesser extent by the other impurities.

Excessive iron content tends toward coarse grain size in the modified (B-32) alloy, which results in inferior mechanical properties. Copper tends to reduce corrosion resistance and impact strength. Silicon above the specified maximum tends to make satisfactory modification difficult.

2. *Physical Properties of Castings.*

	Alloy B-31	Alloy B-32[3]
Ultimate Tensile Strength, Lb. per sq. in. (Min. to Avg.)[1]	17000-20000	24000-28000
Yield Strength, Lb. per sq. in. (Permanent Set=0.2%) (Avg.)	9000	11000
Modulus of Elasticity, Lb. per sq. in. X 10^6 (Approx.)	10	10
Elongation, Per cent in 2 in. (Min. to Avg.)	3.0-8.0	5.0-7.0
Brinell Hardness, 10 mm ball—500 Kg load (Approx.)	40	50
Ultimate Compressive Strength, Lb. per sq. in. (Approx.)[2]	25000	28000
Specific Gravity (Approx.)	2.65	2.66
Weight per cu. in (Lbs.) (Approx.)	0.096	0.095
Pattern Maker's Shrinkage—inches per foot	1/10-5/32	1/10-5/32
Solidification Range—°F (Approx.)	1165-1070	1150-1070
Electrical Conductivity (Percent of annealed copper standard at 20°C) (Approx.)	40	35
Endurance Limit, Lb. per sq. in. (R. R. Moore Machine 500,000,000 reversals)	6500	6000
Coefficient of Thermal Expansion per °F X 10^{-6} (Approx.) 68–212°F	12.2	11.3
68–572°F	13.3	11.9

[1]Tension values determined from standard ½ in. diameter A.S.T.M. separately cast test specimens.

[2]Results of tests on specimens having l/r ratio of 20. All specimens failed by lateral bending.

[3]Modification processes patented U. S. Nos. 1,387,900, 1,410,461, 1,453,928, 1,596.020, 1,570,893, 1,848,797 and 1,848,798.

3. *Conforming Specifications.*

B-31	Aluminum Company of America	No. 43 Alloy
	Society of Automotive Engineers	No. 35 Alloy
	American Society for Testing Materials	No. B26-33T Alloy J
	U. S. Navy Department	46Alc Grade 2
	U. S. Army Ordnance Department	57-72 Grade 1*
B-32	Aluminum Company of America	No. 47 Alloy
	Society of Automotive Engineers	No. 37 Alloy
	American Society for Testing Materials	No. B-26-33T Alloy K
	U. S. Army Ordnance Department	57-72 Grade 8

* Minimum Elongation 3.5%.

4. *Development.*

The common aluminum-silicon alloys were developed to meet the need for improved casting characteristics and corrosion resistance. Alloy B-31 containing about 5 per cent silicon, because of its fluidity is especially suitable for thin section intricate castings. The alloy is widely used for pressure tight castings. The corrosion resistance of the alloy is appreciably better than that of the common aluminum-copper alloys and for this reason finds use in ever widening fields.

Alloy B-32 containing about 12.5 per cent silicon has somewhat similar casting characteristics to alloy B-31 but better mechanical properties. When cast in sand these properties are only possible through a special "modification" process. This process consists of a controlled addition to the molten metal prior to pouring, of certain modifying agents such as sodium.[1]

5. *Field of Use.*

Alloy B-31 is used quite extensively for architectural applications such as spandrels, panels, mullions, and ornamental grille work. It is used for some outboard motor and marine fittings, water jackets, and manifolds. There are numerous industrial applications where pressure tightness and corrosion resistance are necessary and the mechanical properties are adequate.

Alloy B-32 finds limited use in this country because heat treated alloy castings with somewhat better characteristics are available. It is, however, being used quite extensively in Europe for automotive, marine, and machine tool applications.

[1] U. S. Patents 1,387,900; 1,410,461; 1,596,020; 1,848.797; 1,848,798.

E. RECOMMENDED PRACTICE FOR THE HEAT TREATED ALUMINUM-SILICON ALLOYS[1]

1. *Chemical Control Limits.*

Alloy	Cu.	Iron	Si.	Mg.	Mn.	Ni.	Other Elements
B-41 TH1......	1.0-1.5	0.5 max.	4.50-5.50	0.40-0.60	...	...	Total others 0.30% max.
B-41 HT2......	"	"	"	"	...	...	
B-41 HT3......	"	"	"	"	...	...	
B-42 HT1......	0.20 max.	0.5 max.	6.50-7.50	0.20-0.40	...	...	Total others 0.20%
B-42 HT2......	"	"	"	"	...	...	
B-43 HT1......	1.2-1.75	0.6 max.	4.50-5.50	0.40-0.60	0.00-1.00	0.60-1.00	Total others 0.20%
B-43 HT2......	"	"	"	"	"	"	

The tensile and yield strengths and hardness of the aluminum-silicon alloys increase with copper and magnesium content. The addition of these elements much beyond the specified limits results in excessive brittleness. Iron is exceptionally harmful with respect to elongation and should be maintained as low as possible.

The lower copper and magnesium of alloy B-42, together with an increase in silicon over Alloy B-41, reduces the tensile strength somewhat but improves the ductility. Alloy B-42 possesses excellent corrosion resistance.

The addition of nickel and manganese, although reducing the ductility of alloy B-43 at room temperatures, materially improves the mechanical properties at elevated temperatures.

[1] U. S. Patents 1,508,556; 1,572,488; 1,595,058; 1,848,816; 1,908,023.

2. *Physical Properties of Sand Castings.*

	Alloy B-41 HT1	Alloy B-41 HT2	Alloy B-41 HT3	Alloy B-42 HT1	Alloy B-42 HT2	Alloy B-43 HT1	Alloy B-43 HT2
Ultimate Tensile Strength, Lb. per sq. in. (Min. to Avg.)[1]	27000–30000	32000–36000	25000–27000	26000–29000	30000–33000	25000–28000	23000–26000
Yield Strength, Lb. per sq. in. (Permanent Set=0.2%) (Avg.)	20000	27000	23000	16000	22000	24000	21000
Modulus of Elasticity, Lb. per sq. in. X 10^6 (Approx.)	10	10	10	10	10	10	10
Elongation, Percent in 2 in. (Min. to Avg.)	4.0–5.0	2.0–3.0	1.0–2.0	5.0–7.0	3.0–5.0	1.0–2.0	1.0–2.0
Brinell Hardness (10 mm ball, 500 Kg Load) (Approx.)	60	80	60	55	70	60	55
Ultimate Compressive Strength, Lb. per sq. in. (Approx.)[2]	65000	68000	....	46000	48000	....	....
Specific Gravity (Approx.)	2.67	2.67	2.67	2.63	2.63	2.74	2.74
Weight per cu. in. (Lbs.) (Approx.)	0.096	0.096	0.096	0.095	0.095	0.099	0.099
Pattern Maker's Shrinkage, inches per foot	1/10–5/32	1/10–5/32	1/10–5/32	1/10–5/32	1/10–5/32	1/10–5/32	1/10–5/32
Solidification Range—°F (Approx.)	1160–1075	1160–1075	1160–1075	1130–1075	1130–1075	....	....
Electrical Conductivity (Percent of annealed copper standard at 20°C) (Approx.)	35	37	33	....	....	....	....
Endurance Limit, Lb. per sq. in. (R. R. Moore Machine 500,000,000 reversals)	....	7000	....	....	8000	7000	7000
Coefficient of Thermal Expansion per °F X 10^{-6} (Approx.) 68–212°F	12.2	12.2	12.2	11.9	11.9	11.9	11.9
68–572°F	13.3	13.3	13.3	13.0	13.0	12.7	12.7

[1]Tension values determined from standard ½ in. diameter A.S.T.M. separately cast test specimens.
[2]Results of tests on specimens having 1/r ratio of 20. All specimens failed by lateral bending.

3. *Conforming Specifications.*

Alloy		
B-41 HT1	Aluminum Company of America	No. 355-T4 Alloy
	Society of Automotive Engineers	No. 322-HT1 Alloy
	U. S. Navy Department	M-212a Class 10 HT2*
B-41 HT2	Aluminum Company of America	No. 355-T6 Alloy
	Society of Automotive Engineers	No. 322-HT2 Alloy
	U. S. Army Ordnance Department	No. 11307
	U. S. Navy Department	M-212a Class 10 HT3*
B-41 HT3	Aluminum Company of America	No. 355-T51 Alloy
	U. S. Navy Department	M-212a Class 10 HT4*
B-42 HT1	Aluminum Company of America	No. 356-T4 Alloy
	Society of Automotive Engineers	No. 323-HT1 Alloy
	U. S. Navy Department	No. 46A1c Class 3
B-42 HT2	Aluminum Company of America	No. 356-T6 Alloy
	Society of Automotive Engineers	No. 323HT2 Alloy
	U. S. Army Ordnance Department	No. 11308
B-43 HT1	Aluminum Company of America	No. A355-T51 Alloy
	U. S. Navy Department	M-212a Class 11 HT3*
B-43 HT2	Aluminum Company of America	No. A355-T59 Alloy
	U. S. Navy Department	M-212a Class 11 HT2*

* Tentative.

4. *Development.*

The heat treatable aluminum-silicon alloys were developed to combine the excellent casting characteristics of this type of alloy with the improved mechanical properties resulting from heat treatment, the benefits of which are so evident through the use of heat treated aluminum-copper alloys. The silicon alloys are much easier to cast than the latter alloys and at the same time have comparable mechanical properties.

The aluminum-silicon alloys because of their fluidity are especially adapted for intricate castings with thin sections. In addition to this they are not "hot short" and are generally quite leak proof. This group of alloys is more resistant to corrosion than the aluminum-copper alloys. They also possess good machinability and are among the best for electroplating and anodizing (See section A3, Page 8).

5. *Field of Use.*

The heat treatable aluminum-silicon alloys are finding application in ever widening fields, displacing aluminum-copper alloys largely because of their superior casting characteristics and resistance to corrosion. In many cases, their superior mechanical properties make them preferable to the common aluminum-silicon alloys.

These alloys are widely used in Diesel engines for such parts as crankcases, oil pans, manifolds, cylinder heads, and super-

charger equipment. They are used for cylinder heads, manifolds, and housings in automotive engines. The alloys are used in some aircraft engines for cylinder heads, crankcases, jackets, housings, and covers. Alloy B-41 is particularly adapted for liquid cooled cylinder heads requiring in addition to pressure tightness, good mechanical properties at temperatures up to 400 degrees Fahr. Alloy B-43 was developed principally for air cooled aircraft cylinder heads where strength at temperatures from 400 to 600 degrees Fahr. is an important requisite.

The heat treated aluminum-silicon alloys are also employed for air compressor and air brake parts and pneumatic tools. In addition to this, they are used for fans, impellers, tank car fittings, housings and covers for electrical, textile, and foodstuff equipment, as well as many other miscellaneous industrial applications.

F. RECOMMENDED PRACTICE FOR THE ALUMINUM-MAGNESIUM ALLOYS

1. *Chemical Control Limits.*

Alloy	Cu. Percent	Iron Percent	Si. Percent	Mg. Percent	Others
B-61	0.10 max.*	0.40 max.	0.25 max.	3.25-4.25	Total Imp. 0.60%

*U. S. Army Specification 57-72-4—0.05% max.

The excellent physical and mechanical properties of the aluminum-magnesium alloys depend largely upon the purity of the metal. It is therefore essential that iron and silicon content be kept at a minimum to realize maximum mechanical properties and corrosion resistance. Several modifications of this alloy, however, employ 1 to 2 per cent silicon, which is added to improve the casting characteristics. In spite of these additions, such an alloy has excellent corrosion resistance although slightly inferior to alloy B-61.

Copper tends to lower corrosion resistance and, to a lesser extent, mechanical properties.

Iron tends to lower the corrosion resistance and mechanical properties of alloy B-61.

Another modification of alloy B-61 includes 0.5 per cent manganese which is added to improve corrosion resistance. There is some question whether such an addition effects any appreciable change in this factor, although it does tend to reduce the oxidation of the magnesium.

2. *Physical Properties of Sand Castings.*

	Alloy B-61
Ultimate Tensile Strength, Lb. per sq. in. (Min. to Avg.)[1]	22000-25000
Yield Strength, Lb. per sq. in. (Permanent Set=0.2%) (Avg.)	12000
Modulus of Elasticity, Lb. per sq. in. X 10^6 (Approx.)	10
Elongation, Percent in 2 in. (Min. to Avg.)	6.0-8.0
Brinell Hardness—10 mm ball, 500 Kg Load (Approx.)	50
Ultimate Compressive Strength, Lb. per sq. in. (Approx.)[2]	50000
Specific Gravity (Approx.)	2.65
Weight per cu. in.—Lbs. (Approx.)	0.095
Pattern Maker's Shrinkage, inches per foot	1/10-5/32
Solidification Range—°F (Approx.)	1185-1075
Endurance Limit, Lb. per sq. in. (R. R. Moore Machine 500,000,000 Reversals	5500
Coefficient of Thermal Expansion per °F X 10^{-6} (Approx.) 68-212°F.	13.3
68-572°F.	14.4

[1] Tension values determined from standard ½ in. diameter A.S.T.M. separately cast test specimens.

[2] Results of tests on specimens having 1/r ratio of 20. All specimens failed by lateral bending.

3. *Conforming Specifications.*

Alloy		
B-61	Aluminum Company of America	No. 214 alloy
	Society of Automotive Engineers	No. 320 alloy
	U. S. Army Ordnance Department	No. 57-72-4

4. *Development.*

The past few years have witnessed the introduction of an aluminum-magnesium alloy containing 4 per cent magnesium as the major alloying element. This is by no means a new alloy. However, it is only recently since high purity aluminum has been available that the most desirable characteristics have been realized.

Alloy B-61 (4 per cent magnesium) is not susceptible to heat treatment and is therefore used in the "as cast" condition. The outstanding characteristic of this alloy is its exceptional resistance to corrosion and for this reason it is used for applications in which even the aluminum-silicon alloys are unsatisfactory.

Alloy B-61 is somewhat more difficult to cast than many of the previously discussed alloys. Additional precautions in foundry technique must be taken to insure freedom, particularly from shrinkage, dross, and oxidation of magnesium. The alloy is not considered "hot short" and consequently castings can be made with little danger of cracking. The alloy machines quite well although the hardness is not exceptionally high. This alloy is not considered to be especially pressure tight. In this respect, it is inferior to the aluminum-silicon alloys. Proper observance of certain phases of foundry technique, however, will tend to materially improve this condition.

The alloy is capable of taking a very excellent polish and is especially adapted to anodic finishes (See section A3).

5. *Field of Use.*

Alloy B-61 is finding extensive application where maximum resistance to corrosion and discoloration is desirable or necessary. The alloy is used for cooking utensils, dairy and plumbing equipment, pipe fittings and valves, and cash register and railway car fittings. Since the alloy takes a high polish and is well adapted to anodizing, it is used for vending machine parts and ornamental architectural castings.

Heat Treatment of Cast Iron

By R. G. McElwee*, Ecorse, Mich.

Abstract

The author discusses heat treatment from three angles, first for lowering hardness, second for increasing hardness, and third, controlling hardness by special irons. Under the second heading, he discusses iron of martensitic structure and its application for various types of castings. Under special irons the author uses as an example one containing approximately 2.5 per cent carbon, silicon 1.5 per cent, and manganese 0.35 per cent. This iron is cast white and on heat treating produces a tensile strength of 90,000 lb. per sq. in., an elastic limit of 70,000 lb. per sq. in., with an elongation of approximately 4 per cent and hardness of 235 Brinell.

1. Within the past few years a large number of papers have been written regarding the heat treatment of cast iron and some of them have added very materially to the published data on this very interesting subject. A review of those outstanding has disclosed the fact that most of them have been concerned primarily with the theory of the change in structure accomplished by the heat treatment. It has therefore been thought desirable in this paper to deal with the subject from a very practical standpoint, covering, if possible, the many varied uses to which this knowledge can be put, especially to enumerate the types of work particularly applicable to this process.

2. To accomplish our purpose, therefore, it has been decided to divide the paper into three parts, as follows.

a. Heat treatment for lowering hardness
b. Heat treatment for increasing hardness
c. Heat treatment of special irons

3. In dealing with a large number of customers, a jobbing

* General Manager, Ecorse Foundry Co.

Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

foundryman finds that while the simple annealing treatment for the lowering of Brinell hardness has been very well described in most of the handbooks and papers dealing with this subject, there is still a great deal of confusion in the minds of some, particularly as to the difference between the so-called normalizing or strain removing treatment and the actual annealing treatment.

4. In order to write any heat treatment specifications intelligently, whether they be for lower or increased hardness, we must take into account the lower *Ar* point on the cooling curve which has been definitely established for this type of cast iron, being given in the Cast Iron Symposium[1] as 1340 degs. Fahr., and which has been surveyed by Bolton for ordinary irons and established as being between 1325 and 1340 degs. Fahr. This is the point of transformation, or the point at which graphitization takes place most readily. It should be remembered, however, that iron will graphitize below this point if the time is extended over a long period. This temperature does indicate the point or region above which we must go if we desire to put the carbon back into solution; it represents the line which must not be passed if we desire to prevent the re-solution of the carbon.

HEAT TREATMENT FOR LOWERING HARDNESS

5. Most users of cast iron have found that, in order to be perfectly safe, taking into account errors of reading temperature and various other factors beyond control, a specification of approximately 1000 degs. Fahr., is sufficiently high to completely relieve casting strains without changing the microstructure.

6. If it is desired to lower the Brinell hardness this must be accomplished by redissolving some of the combined carbon, which is precipitated as graphite at or above this critical point during the subsequent cooling. The temperature is run ordinarily somewhat above this point on the curve to dissolve the carbon more readily, and on account of the relatively high silicon content of most cast irons the graphitization takes place rather rapidly. Ordinarily, therefore, it is not necessary to hold at a temperature for re-solution for any great period. This is particularly true when alloys which stabilize the carbides are not present.

7. For plain cast irons we suggest the temperatures and times shown in Fig. 2 for a reduction of hardness, and suggest that, in

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[1] *Symposium on Cast Iron*, American Foundrymen's Assn. and American Society for Testing Materials, 1933.

the presence of an alloy, the maker of the particular alloy involved be consulted with information as to the softening effect of time-temperature without the alloys, permitting him to make the differential necessary in the case of the alloy which is involved.

Heat Treatment for Increasing Brinell

8. Recently disseminated knowledge about the effect of alloys has made possible the effective use of heat treatment to produce a material usually martensitic in structure, which is quite rapidly taking the place of carburized steel for certain applications. It is particularly desirable to use this method of producing hard parts

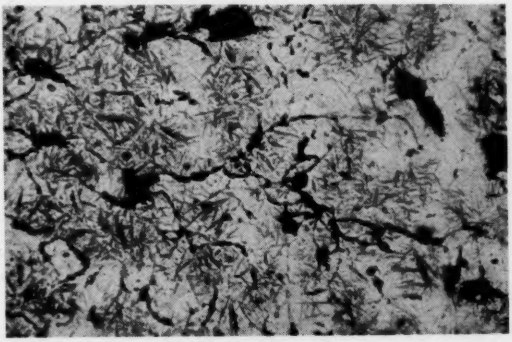

Fig. 1—Structure of Alloyed, Heat Treated Iron. Composition: T.C. 3.21, Si. 2.21, Cr. 0.69, Mo. 0.75 (calculated). Brinell As-Cast, 241. Quenched in Oil From 1550 Degrees Fahr., Giving Brinell of 532 (x 200).

where the design is such that it can be more readily cast than machined from a solid chunk.

9. The quench-draw treatment usually used for this purpose has a wide variety of applications, and for those interested in the application of this material to Diesel sleeves reference is made to the excellent work done by W. P. Eddy, Jr., described in a paper[2] presented at the 1934 Philadelphia convention. The analysis suggested by Mr. Eddy makes use of chromium and nickel to produce a structure which can be quenched to a martensitic state to give the physical properties desired in that particular design.

10. It has been found that an analysis approximately as outlined below will give similar properties. In fact, Fig. 1, which is

[2] Eddy, W. P., Jr., *"Heat Treated Gray Iron Cylinder Liners,"* Trans. A.F.A., Vol. 42 (1934), pp. 129-147.

taken at 200 diameters, illustrates the very good martensitic structure which can be produced with such an analysis. The analysis of the specimen of Fig. 1 is as follows:

ELEMENT	PER CENT
Total Carbon	3.00 to 3.20
Manganese	0.60 to 0.80
Phosphorus	0.15 Max.
Sulphur	0.08 Max.
Silicon	1.80 to 2.00
Chromium	0.50 to 0.60
Molybdenum	0.60 to 0.75

NOTE: From 1 to 1.75 per cent nickel may be substituted for the molybdenum in this analysis.

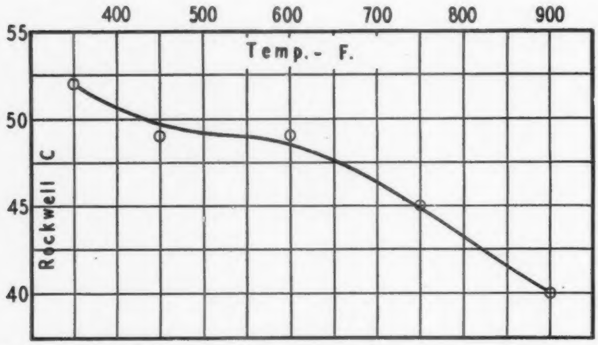

FIG. 2—ROCKWELL HARDNESS AS AFFECTED BY DRAWING TEMPERATURE FOR AN IRON OF THE COMPOSITION OF FIG. 1.

11. This particular analysis is one that is being used for a casting which is 3½ inches in diameter, cast solid. We suggest a slight increase in the silicon and working to the lower limit of chromium and molybdenum if the section is less than one equivalent to 3½ inches in diameter. As cast in the section mentioned, the Brinell hardness is approximately 235 to 248. Quenched from 1500 degs. Fahr., this material should show a Rockwell C hardness of 53 to 56. Tempering can be accomplished by heating to 450 to 900 degs. Fahr. for approximately 2 hours, which will drop the Rockwell *C* hardness as indicated on the chart, Fig. 2. Tensile strength as cast is 49,000 to 51,000 lb. per sq. in.; after tempering 45,000 to 65,000 lb. per sq. in. depending on temperatures of draw.

Specific Applications

12. The principal interest in this particular type of iron and

its practical use is in the fitting of it to definite requirements and applications. Many of the following parts are actually in production, and others have been definitely demonstrated, although the jobs are not running.

13. *Patterns:* It has been found very advantageous to use a material of this type for high production patterns, especially for stripper plate equipment on those jobs which require a very large number of pieces to be produced from a pattern. It can be expected that the life of an equipment made in this manner will be at least three times the life of an ordinary cast iron pattern

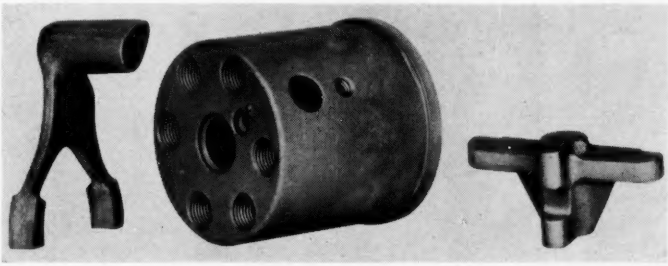

Fig. 3—Heat Treated Parts. Center—Fuel Injection Pump of Material of Fig. 1, with Rockwell C Hardness of 46 to 48, After Heat Treatment. Left and Right—Parts of a Landing Gear for Aeroplanes. Material Similar to That of Fig. 5, Quenched and Drawn Two Hours at 1250 Degrees Fahr.

without heat treatment. By working on the low limit of silicon for any given section, it is possible to minimize the distortion and growth. It has been entirely practical to make patterns for this process, thus effecting considerable saving over a long period, although the cost of fabrication of the pattern will be slightly higher, due to the fact that some finishing must be done after quenching.

14. *Fuel Injection Pumps:* A particular application is a fuel injection pump stator (Fig. 3), in which assembly the rotor is made of nitrided steel. In this particular case the wear resistance has been equal to or better than the nitrided rotor. The work has a hardness of about 48 Rockwell, after treatment.

15. *Aircraft Gears:* An illustration is also offered of some parts (Fig. 3) used with a retractable landing gear for airplanes, in which it is necessary to produce a hardness of approximately 40 or higher on the clutch dogs, with a hardness of approximately 30 in the gear teeth. This was accomplished by heating to 1550 degs. Fahr. and quenching on a watercooled flat plate. The process

mentioned seems to be entirely feasible for that type of work in which it is possible to quench the solid rather than in a liquid.

16. *Locks:* Although the type of tire lock which necessitated a separate casting is obsolete, there are still lock applications in which the case is most readily made by the casting process, and if quenched to produce a high hardless will be reasonably resistant to cutting by readily portable tools.

17. *Rollers:* Rollers which have been used for supporting a

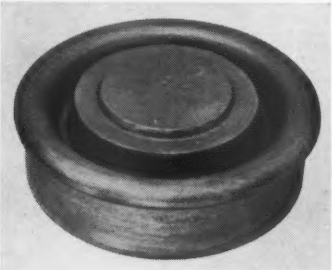

FIG. 4—ROLLER FOR ELECTRIC FURNACE MADE FROM MATERIAL SIMILAR TO FIG. 1. HARDNESS AFTER HEAT TREATMENT, ROCKWELL C, 45 TO 50. (HALF SIZE.)

rocking furnace must be resistant to wear. These carry the entire weight of the furnace load and the weight of the furnace, and operate on a steel track. An illustration is presented (Fig. 4) showing approximately the size and section in which this roller is made. In service it has proven entirely satisfactory. The Rockwell hardness is approximately 48 *C*.

18. *Roller Bearing Pulleys and Wheels:* On account of the high resistance to deformation which accompanies the high hardness numbers obtainable, it is entirely feasible to make very accurate pulleys and wheels which can be internally ground after the hardening operation, the hard surface providing an entirely acceptable surface against which the rollers can operate.

19. *Gears:* In general, gears for many purposes, as well as sprockets made by a quench treatment show exceptional resistance to wear. By a proper control of composition, that is, by holding the silicon low, the over all distortion is so slight and consistent that it can be compensated in cutting the gear. There are instances on record of 10-in. pitch diameter gears showing a growth of less than 0.01 in., due to heat treatment.

20. *Cams:* It is obvious that cams for many purposes can be made advantageously of this material. These cams find particular application in the machine tool industry, and for larger gas and oil engines, in which the cam is made as a separate unit from the shaft.

21. *Forming Dies:* Dies for forming sheet metal can be made by this process, and when polished show an extremely high finish, which ordinarily will give many times the number of stampings before being worn beyond the useful life of the die. This field is particularly fertile for this kind of material.

22. *Jig Bushings:* For certain types of work, jig bushings, especially large ones, can be made more advantageously from cast material than they can be machined from the bar or tube, it being possible to produce a Rockwell hardness of 50 *C*. Most applications requiring jig bushings will find this material particularly adaptable.

23. *Cranks:* As a replacement material for carburized steel there is no reason that this type of cast iron, properly hardened, cannot be used for many types of compressors and refrigeration cranks. The range of heat treatments and effect of tempering makes it possible to secure the proper combination of hardness and strength. It is very well known that in addition to taking an extremely high polish the material shows a very high resistance to wear in this sort of lubricated application.

24. *Molds:* Molds for many types of materal, including brick molds and molds for various plastics, which require a high polish, can be made advantageously of a material in which the labor can be kept to a minimum, due to the ability of the foundryman to cast practically to size and form, thus leaving a minimum amount of labor to be performed in the preparation of the mold.

25. Many other applications will suggest themselves, particularly those which require a combination of reasonably high strength with an extremely fine finish and resistance to wear. There is little question but that as we become more familiar with the possibilities of varying of heat treatment to produce specific results, hardened cast iron will find a great many applications which are now being limited to certain other types of material in which the process of manufacture is considerably more expensive. It must be remembered, however, that the heat treated part will contain any of the casting defects of the original casting, and it therefore becomes necessary for the foundryman to use extreme

caution in the matter of gates, risers, and mechanical handling of metal to produce the very best possible casting as a basis on which to build.

26. The third general heading listed earlier in this paper covers the heat treatment of special iron, and under this heading we wish to discuss one particular type of iron which seems to have a very large potential field, on account of the wide variation of physical properties possible by heat treatment. This type of iron, which is being produced in the air furnace as well as in the electric furnace, is being sold under several trade names with some slight variation in method of manufacture, and also with some variation in the microstructure accomplished by the heat treatment.

27. This iron is one containing a total carbon of approximately 2.50 per cent, silicon approximately 1.50 per cent, manganese 0.35 per cent, and a maximum sulphur and phosphorus allowance of 0.05 per cent. The silicon of course will vary according to the section being produced and the time required for heat treatment will vary considerably with the section. The heat treating cycle to be described is one which is used for sections of approximately $\frac{1}{4}$ to $\frac{3}{8}$ inch.

Factors of Composition

28. Before describing the heat treatment it might be well to indicate the reason for the proportion of elements in the composition. Experimental work was done with various amounts of carbon beginning at $1\frac{1}{2}$ per cent, and while some test bars were made with the $1\frac{1}{2}$ per cent carbon material, it was found impractical to make castings commercially with this type of analysis. The liquid shrinkage was extremely bad, and in many cases it was found impossible to produce sound castings.

29. The experiments were conducted running progressively higher carbon, until what seemed to be an ideal compromise was reached, that is, a compromise between castability and physical properties. The object of the foundry is to keep as constant a total carbon as possible, in order not to complicate the heat treatment problem. It was therefore decided to run $2\frac{1}{2}$ per cent carbon in all castings regardless of section. The silicon should run from 1.30 per cent in sections $\frac{3}{4}$ in. to 1 in. thick, up to 1.60 to 1.70 per cent for sections 3/16 in. thick.

Physical Properties

30. The heat treatment cycle depends upon the physical properties desired. The range of tensile strength possible is from 55,000 to 100,000 lb. per sq. in. The elongation, generally speaking, will vary inversely as the tensile strength. A 55,000 lb. per sq. in. iron, properly heat treated, should show an elongation of 12 to 15 per cent, and a 100,000 lb. per sq. in. iron should show an elongation of 3 or 4 per cent. The elastic limit seems to be approximately 75 per cent of the ultimate, regardless of the method of treatment and the elongation.

31. This iron is cast white, and, if it is desired to experiment with the optimum mixture, the theory is that the silicon should be just sufficiently high to produce a white iron in the casting. The nearer a mottled iron can be approached without actually showing the mottle, the more perfect will be the response to heat treatment.

Typical Heat Treatment

32. A typical heat treatment for producing the lower strength higher elongation material is as follows:

4 hours at 1725 degs. Fahr.
Cool to 1325 degs. Fahr.
Hold at this temperature 4 hours.
Furnace cool to 1100 degs. Fahr.
Air cool.

33. This specification for heat treatment has been written to be given to the commercial heat treater. What actually is desired at the stop-off on the way down is that the load shall pass through the lower critical as slowly as possible to accomplish the greatest amount of graphitization. The time of dropping from 1725 to 1325 degs. Fahr. is not important; except from a commercial angle, it should be dropped as rapidly as possible.

Other Heat Treatments

34. Better physical properties can be obtained by heating to 1725 degs. Fahr. for 4 hours, cooling in the furnace to about 1500 or 1550 degs. Fahr. oil quenching, and then reheating to about 1275 degrees and holding at this temperature for varying lengths of time, depending upon the properties desired. Complete malle-

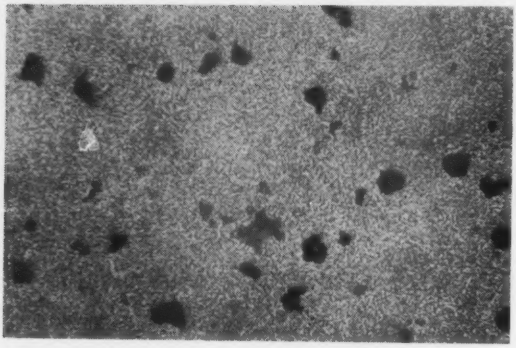

FIG. 5—MICROSTRUCTURE OF AN IRON CAST WHITE, QUENCHED AND DRAWN. 2.50 PER CENT T.C., 1.50 PER CENT SI., TENSILE STRENGTH 75,000 TO 80,000 LB. PER SQ. IN., BRINELL HARDNESS 223 TO 235, PER CENT ELONGATION 3 TO 5 (x 150).

abilization will take place at approximately 12 hours. The iron is spheroidized by this process, the result of the quench being a sorbitic pearlite. A 1-hour draw at 1325 degs. Fahr. discloses, at high magnification, a very perfect spheroidization.

35. The combined carbon drops throughout the heat treatment and the spheroids becoming fewer, until at about 12 hours the combined carbon is practically gone. Physical properties, both elongation and strength, will be about 5 or 10 per cent higher by the quench treatment than by the slow cooling treatment described first.

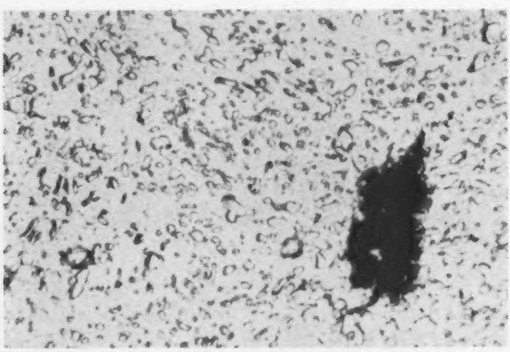

FIG. 6—MICROSTRUCTURE OF MATERIAL SIMILAR TO THAT OF FIG. 5 GIVEN SPHEROIDIZING TREATMENT, DRAWN 4 HOURS AT 1250 DEGREES FAHR. AFTER OIL QUENCH (x 1500).

Structures and Properties

36. Micrographs are shown, indicating the condition of this material after a 1 hour draw (Fig. 5) and after 4 hours (Fig. 6). After a 1 hour draw the following physical properties should be expected:

Tensile Strength, lb. per sq. in.	90,000
Elastic Limit, lb. per sq. in.	70,000
Brinell Hardness (Approximate)	235
Elongation, per cent (Approximate)	4

37. As might be expected, experience has proved that the wear resistance of this iron is comparable to that of good high test

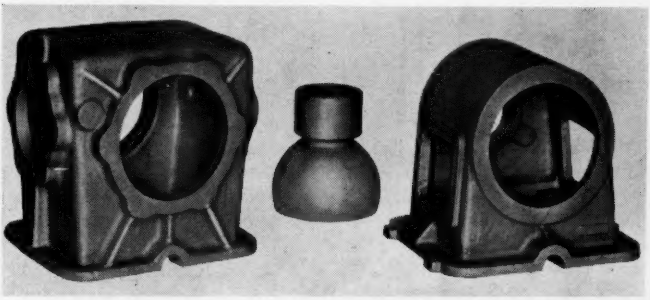

Fig. 7—Castings of Material Similar to Fig. 6. Transmission and Joint Parts for Tandem Drive for Motor Truck. White As-Cast, Heat-Treated for Spheroidized Structure.

gray irons, the spheroids or carbides apparently furnishing a support for the load as we expect the plates to do in lamellar pearlite.

38. Physical properties of this iron, particularly in the quench treatments, can be improved by the use of molybdenum or nickel. It is extremely important that no chromium be present if a minimum time is desired for the heat treatment cycle. The stabilization of the carbides by chromium is easily detected if the chromium exceeds 0.05 per cent in the charge.

39. Illustrations are shown (Fig. 7) of several parts which are being made from this material. The transmission case illustrated is a particularly difficult job, it being necessary to produce physical properties of the order of steel castings to meet the engineering requirements for this application.

40. The following references are offered for those who desire

to make a more thorough study of the theory of the heat treatment of cast iron:

Hurst, J. E., "*Heat Treatment of Cast Iron,*" IRON AGE, vol. 132, Oct. 26, 1933.

Bolton, J. W., "*Heat Treatment of Cast Iron,*" FOUNDRY, March 1935.

Ballay, Marcel, "*Contribution to Study of Martensitic Quenching of Alloy Cast Iron,*" TRANS. A.F.A., vol. 40, 1932, pp. 1-15. Also FOUNDRY, vol. 60, no. 7, May 1932, pp. 36, 37, 64 and 66.

DISCUSSION

A. L. BOEGEHOLD:[1] There is only one point I would like to make about heat treated iron that is cast white. These irons, cast white and then annealed, are really not gray cast irons as we ordinarily consider them. I think this point should be made clear to prevent any misunderstanding upon the part of those not perfectly familiar with these irons. There are other ways of obtaining the same results with the materials that we have had for a long time. An ordinary malleable iron that has been completely annealed may be heat treated to produce about the same physical properties as cited by the authors. The same structures may also be obtained more rapidly in castings having light sections by increasing the silicon somewhat, taking advantage of the faster cooling rate occurring in lighter sections to get the white structure as cast even with the higher silicon.

The same thing as was shown in Mr. Phillips' paper* can be done, even in heavier sections, by adding suitable alloys along with higher silicon content, to get a white structure as cast. Once having obtained the white structure as cast, it is possible to anneal either completely or to get some type of spheroidized pearlitic structure, or lamellar pearlitic structure, depending upon the properties desired.

DR. H. A. SCHWARTZ:[2] Are these irons referred to in paragraph 29, which are given as white in certain sections, with silicon some 60 or 70 points higher than malleable iron, white merely because of the thinness of the section in the sand mold, or are they artificially chilled, as was suggested by Williams quite some years ago?

A second question. When the particular automobile part is cast in its malleable design, for which purposes these spheroidized materials apparently are identical with the pearlitic malleable of the malleable trade,

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[1] Metallurgist, General Motors Corp., Research Division, Detroit, Mich.

[2] Manager of Research, National Malleable and Steel Castings Co., Cleveland, Ohio.

*PHILLIPS, G. P., "*Impact and Other Physical Properties of Alloy Cast Irons,*" TRANS. A.F.A., vol. 43, pp. 125-142 (1935), also vol. 6. No. 6, Dec. 1935, pp. 125-142.

how did its machining rate appear to be affected as compared to its malleable state?

G. P. PHILLIPS:[3] I believe that the application of heat treated cast iron, both the material that is cast white and annealed in a short period of time and the material that is hardened by quenching and drawing, is going to be used in increasing quantities. In the automotive field, particularly in commercial vehicles, cylinders of the engines of the future probably will all be hardened and used in conjunction with hardened piston rings, the increased cost of which probably will be partially offset by the use of ordinary soft gray iron for the cylinder block. In any place where exceptional wear resistance is desired, it seems to me that the hardened material certainly will find a big field of application.

A. J. HERZIG:[4] I wish to interject a word of caution which is that in designing, using this material, do not design on a basis of a modulus of 35,000,000 lb. per sq. in. You will not get such a modulus with this material.

F. J. WALLS:[5] Another possibility of heat treatment that has not been mentioned here is the possibility of heat treating metal after pouring in the mold itself. I think such type of heat treatment is something the foundryman has neglected. Directional solidification and other heat treatments of the castings immediately after pouring and before complete solidification should be given a great deal of consideration.

F. D. O'NEIL:[6] Regarding this time of holding at 1725 degrees Fahr., providing you went to a higher total carbon material, what effect would that have on the time of holding? For instance, take cupola metal with 3 per cent total carbon in place of 2.50 per cent total carbon iron mentioned by the author. Would it take longer to precipitate the graphite in this case?

MR. MCELWEE: Dr. Schwartz asked two questions: One, about whether the white iron was white in a green sand mold, or whether it was artificially whitened, that is, held white by casting against a chill. No chill was used in the particular case referred to. We are aware of the fact that a great many people think it rather unusual to cast an iron of 2.50 per cent total carbon and 1.50 and 1.60 per cent silicon in a section of a quarter or three-eighths of an inch and get a casting without primary graphite. However, this is done and done every day. We have been doing it for about 4 years. I will say that there are some little tricks to it. We can cast the same analysis and have a great deal of primary graphite. One of the important points is the calculation of the charge. This iron is really synthetic iron made in an electric furnace. Steel comprises about 75 per cent of the charge—the remainder is high silicon pig. If we attempt to arrive at an analysis by using cast iron scrap or a different type of charge, we have difficulty running the silicon that high.

In the case of the differential carrier cited, the question was asked whether the machining rate was affected. I believe that it was not as

[3] Metallurgist, International Harvester Co., Chicago, Ill.
[4] Climax Molybdenum Co., Detroit.
[5] International Nickel Co., New York City.
[6] Western Foundry Co., Chicago, Ill.

high, although the difference was not great enough to be any great factor in deciding on the use of the material. A completely malleabilized iron was used at first, showing a Brinell hardness of 130, and this material showed a Brinell hardness of 180 or 190.

With regard to Mr. Phillips' comment on the future use of this type of material, particularly hardened material for automobile use, I think it is obvious to those who have connections with truck and bus Diesel engine trade, that they are constantly going to the harder type of casting for their application, and it seems only reasonable to suppose the passenger car trade will follow.

I was a little surprised at the question of the 35,000,000 lb. per sq. in. modulus of elasticity coming into the discussion because I thought that point had been settled. I thought we were all agreed on staying under 30,000,000 lb. per sq. in. In fact, from the results that we have on this material, as far as modulus of elasticity is concerned, the spheroidized pearlite material runs quite consistently about 28,000,000 lb. per sq. in. modulus of elasticity in the tensile test and somewhere between 21,000,000 and 25,000,000 lb. per sq. in. modulus of elasticity as determined by the transverse test.

Answering the last question, regarding the total carbon, I would like to go back and state how this amount of total carbon was decided. The first experiments for this type of iron were made on iron containing 1.50 carbon and 1.50 silicon. We made some excellent test bars but found we could not make a casting at all with this material. The shrinkage properties were so bad it was impossible to make castings. So we gradually increased the total carbon until we arrived at 2.50 and then made the silicon balance it in such a way that we backed off 10 or 15 points from that point. We have constantly kept the silicon as high as we dared without making primary graphite. We backed off a little from where primary graphite begins to show. I see no reason for feeling that a higher total carbon would give any difference, excepting for the fact that would necessarily lower the silicon, which probably would extend the time slightly. Obviously, a higher total carbon would result in lower silicon. We keep within that zone, and in that way affect the annealing time to a certain extent. A 3 per cent total carbon would probably indicate lowering the silicon 20 to 30 points, which might extend the time at 1725 degrees Fahr. as much as 50 per cent or even more.

Endurance Limit of Black-Heart Malleable Iron

By E. G. Mahin,* Notre Dame, Ind., and
J. W. Hamilton,** South Bend, Ind.

Abstract

To supply the need for fatigue data on malleable castings, subjected to repeated or reversed stresses, a determination of endurance limit has been made and is here reported. Specimens were of the Farmer type, tested in a transverse rotating beam machine. The endurance limit was found to be higher than the few tests already on record have indicated. A brief discussion of the form and possible influence of graphite nodules is included.

1. Most of the physical and mechanical properties of malleable cast iron have been rather thoroughly investigated, and with surprisingly good agreement, considering the essentially heterogeneous microstructure of this material. The lack of wide variations in mechanical strength characteristics is no doubt due to careful selection of material, adjustment of composition and care in casting and annealing, prevalent in modern malleable foundry practice.

2. In the Symposium on Malleable Iron Castings,[1] average and extreme values for most features of mechanical strength are tabulated and discussed, but little information has been available concerning the endurance limit, under alternating or reversed stresses. This investigation was undertaken to supply this need for information.

3. In the very brief discussion of the fatigue properties of

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** Metallurgist, Bendix Products Corp., and formerly graduate student, University of Notre Dame.

[1] Reprint, June 26, 1931, American Foundrymen's Association and American Society for Testing Materials. Also Proceedings, A.S.T.M. vol. 31, pt. 2, 1931, pp. 319-433.

Note: This paper was presented at a session on Malleable Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

malleable iron, noted in the Symposium,* it is stated that only one careful determination of this property is on record and that the endurance limit, determined upon iron slightly above A. S. T. M. Specification A 47-30 and using a rotating-beam machine of the Farmer type, was found to be between 25,000 and 26,000 lb. per sq. in. The specification of above number gives minimum values as follows:

Ultimate Strength in Tension.......50,000 lb. per sq. in.
Yield point......................32,500 lb. per sq. in.
Elongation in 2 inches....................10 per cent

4. It is understood that the fatigue test to which reference is made in the Symposium is that of Flagle, briefly discussed by Schwartz.[2] In this brief discussion by Schwartz it is stated that the endurance limit of malleable iron is at a fiber stress of 25,000 lb. per sq. in.

5. H. F. Moore has reported[3] tests upon two specimens, with the following results:

	Fiber Stress, lb. per sq. in.	Number of Cycles
(1)....................	23,400	1,336,900
(2)....................	24,150	1,530,700

These determinations were not made as a part of a complete investigation but, for the iron tested by Moore, even the lower stress value was evidently considerably above the endurance limit of the material.

MATERIAL USED

6. The specimens used in the present investigation were of American blackheart malleable iron, prepared and supplied by Cadillac Malleable Iron Co., Cadillac, Mich., through the courtesy of R. J. Teetor, who supplied also the chemical analysis and tensile test data, the latter having been obtained upon the A. S. T. M. standard test bar, cast and annealed under conditions identical with those obtaining with the fatigue test bars. It is assumed that the tensile tests were conducted, as usual, upon the cast and annealed bar, without previous machining. The test data thus supplied are given in Table 1.

7. Each specimen, after breaking in the fatigue testing ma-

[2] Schwartz, H. A., "American Malleable Cast Iron," p. 322 (1922).
[3] Private communication to the authors.
* P. 33.

Table 1

TENSILE PROPERTIES OF MALLEABLE IRON USED FOR FATIGUE TESTS

Physical Test data

Ultimate strength in tension	55,340 lb. per sq. in.
Yield point	35,500 lb. per sq. in.
Elongation	18.5 per cent

Composition

Silicon, per cent	1.00
Carbon, per cent	2.44
Manganese, per cent	0.31
Sulphur, per cent	0.072
Phosphorus, per cent	0.168

chine, was examined to determine the possible presence of defects at the fracture, after which it was sectioned and examined on the microscope. Figure 1 shows a structure which was representative of all pieces tested. An inspection of this photomicrograph will show that the specimens were of sound and normal microstructure, free from unusual flaws and of uniform ferrite grain structure and graphite distribution. No traces of pearlite were found in any of the test specimens.

8. One of the specimens broke away from the mid-point, due

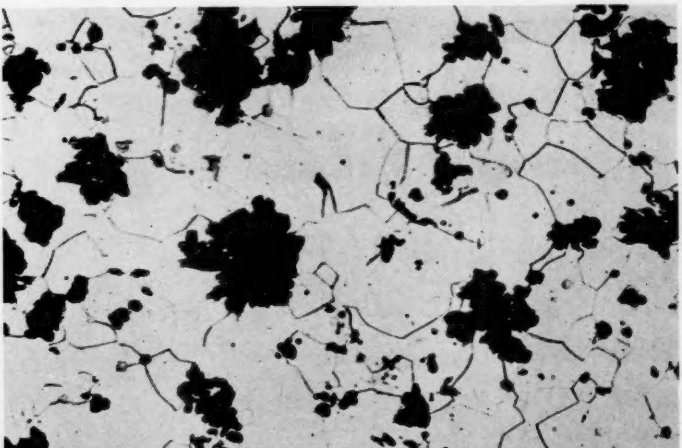

FIG. 1—PHOTOMICROGRAPH OF SECTION OF MALLEABLE IRON SPECIMENS, NITAL ETCHED. X170.

to an internal flaw. The value obtained for this specimen is indicated on the graph sheet but it is not used in plotting the diagram.

9. The testing machine employed was the R. R. Moore rotating transverse beam machine. The specimens were as prescribed for this machine, turned on a radius of 9⅞ inches and polished with No. 00 emery cloth.

10. In Table 2 are summarized the results of the tests of eleven fatigue specimens. The test results are plotted in Fig. 2, *S* against *log N*.

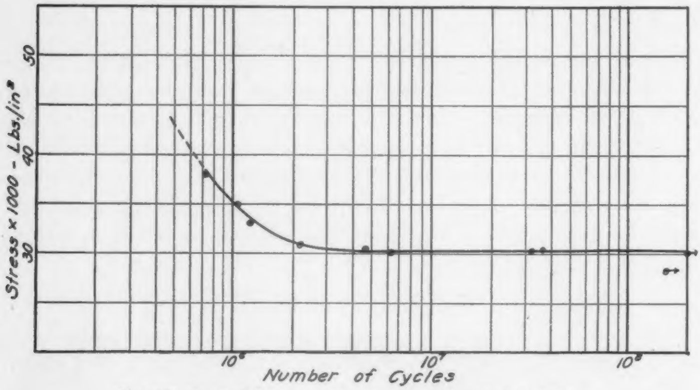

FIG. 2—STRESS-CYCLE RELATIONS OF MALLEABLE IRON.

Table 2

STRESS-CYCLE RELATIONS OF FATIGUE TEST SPECIMENS

Specimen No.	Unit fiber stress, lb. per sq. in.	Cycles to Failure
1*	30,098	32,382,600
2**	27,976	150,000,000
3	31,979	2,323,800
4	30,959	32,229,500
5	30,580	6,280,000
6**	30,027	205,700,000
7	37,600	722,300
8	31,177	4,785,600
9	35,000	1,090,500
10	33,033	1,459,700
11	31,154	36,060,000

* Broke off center. Defective.
** Unbroken.

Discussion and Conclusions

11. Excluding specimen No. 1, which proved to be defective, the tabulated test data and the *S*-log *N* graph indicate an endurance limit, for this class of test, of slightly higher than 30,500 lb. per sq. in. Considering probable slight variations, even in well made castings, a value of 30,000 lb. per sq. in. appears to be safely within the endurance limit. This is distinctly higher than the few values previously reported. The endurance ratio of the material used in these tests is 0.54.

12. From a consideration of microstructure alone, these values may seem surprisingly high. If it be true that fatigue failures usually start at points of high stress concentration, due to the presence of microscopic defects, it would appear that nodules of graphite might readily provide such potential starting points.

13. The theory has been advanced that, on the contrary, the cavities occupied by graphite nodules serve to *arrest* cracks, somewhat as holes drilled through a plate at the ends of cracks arrest further spread of the cracks by diminishing stress concentration. It is the opinion of the present authors that the excellent endurance properties of malleable iron cannot be ascribed to this effect, or at least to only a very minor degree. An internal crack must be presumed to spread in various directions transverse to the axis of the piece. It is true that a cavity lacking sharp points might temporarily arrest the progress of the crack in that portion of the outline of the spreading crack temporarily occupied by the cavity. But it could scarcely prevent—or even materially affect—the spread of the crack in the remaining portion of its advancing frontier, where stress concentration is as severe as before. When this portion of the frontier has passed the granule of carbon it would be expected to reunite. The hole drilled through a plate at the end of a crack is quite another case. Here the entire advancing front of the crack enters the hole and this, through increase of radius of curvature at the end of the crack, arrests the progress of failure.

14. It does not seem probable that the presence of graphite in malleable iron assists in any way in raising the endurance limit. If a crack has once started and if it has proceeded far enough to

encounter several graphite nodules, it will certainly continue to spread, although it is conceivable that, with a given unit fiber stress, a somewhat larger number of cycles of stress repetition might be required to cause failure. This might slightly alter the form of the *SN* graph but it would not raise the indicated endurance limit of the material.

15. We are here interested rather in accounting for the fact that a material as essentially unsound as malleable iron can have so high an endurance limit. The conclusion seems warranted that the metallic phase actually does have good resistance to repeated or reversed stresses and that the absence of sharp projections on the graphite nodules simply prevents these nodules (or the cavities occupied by them) from acting as starting points for failure, or from materially assisting in the spread of cracks.

16. Metallographists have repeatedly called attention to the fact that the proper polishing of sections of either malleable or gray iron is a difficult matter, unless special technique is employed. Graphite is easily removed by the polishing operation. If it were cleanly removed, the form of the cavity which it has occupied might still be easily examined and studied. Two actions serve to confuse one in this attempted study: (1) The edges of the cavity are worn away and their outline changed by the polishing action. (2) Graphite is brushed out over the metal surface surrounding the nodule and it refuses to be detached. A study of numerous photomicrographs, published in various connections, will indicate the greatest diversity of apparent form of graphite nodules, varying in all degrees between spots of quite smooth and rounded graphite and spots of sharp and "brushy" outline.

17. Neither of these forms is truly indicative of the physical shape of the nodule. These nodules do have numerous branches but such branches are, almost without exception, rounded at their ends, thus serving to reduce stress concentration.

18. The photomicrograph of Fig. 1 is of a section which was polished on an automatic machine. A suspension of Fisher's No. 3 alumina was used on a cloth known as Selvyt, a special cotton velvet of short pile. In this automatic machine a very light and uniform pressure is used, the mounted specimen con-

stantly turning so that continuous polishing in any one direction never occurs. While the section so prepared is not mechanically perfect, the true outlines of graphite nodules are quite faithfully preserved.

19. It is possible that the endurance limit of malleable iron, as determined in this investigation, is higher than would be observed on malleable castings in general. Even if this be true, it has at least shown a quality that is possible to be attained, in careful foundry practice.

DISCUSSION

CHAIRMAN R. J. TEETOR:[1] The endurance property of malleable cast iron is a most important property to consider, because of the fact that there are very few published data on it. A very valuable feature of the quality of malleable iron is the apparently high endurance values.

DR. A. DI GIULIO:[2] The authors are to be congratulated for furnishing us with these data on malleable iron. Their contribution becomes even more important when one considers the fact that malleable iron is increasing in its use. The values given by the authors are, however, somewhat higher than those reported by Professor H. F. Moore. The difference in these values may be accounted for either by the difference in chemical composition, the difference in the method of production of white iron or the difference due to the annealing cycle followed.

In paragraph 17, the statement is made that the branches of the graphite nodules are rounded at the ends, thus serving to reduce stress concentration. While that may be the impression obtained from Fig. 1, it is the general experience that higher magnifications are usually necessary to establish or clearly distinguish the ends of the graphite nodules. The available literature will show that the shape of the nodules is primarily dependent on the rate of migration of the carbon which, in turn, depends on superheating of the white iron, the amount of silicon present, and the maximum temperature in the annealing side. It is generally true that irons annealed at low temperature will show rounded graphite particles, while irons annealed at a higher temperature will show graphite of more elongated type. As an interesting case, I believe Dr. H. A. Schwartz,** in 1925, published some pictures of low temperature iron where the graphite particles are very rounded. Then a paper by Schneidewind and White,* shows that increasing the amount of silicon will give a different type of graphite in the final product.

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* WHITE, A. E., AND SCHNEIDEWIND, R., *"Effect of Superheating on Annealing of Malleable Iron,"* TRANS. A.F.A., vol. 41, (1933), PP. 98-109.

** TRANS. A.S.S.T., July 1926, Fig. 5, p. 890.

[1] Cadillac Malleable Iron Co., Cadillac, Mich.

[2] Ford Motor Co., Detroit, Mich.

Some experiments made at the University of Michigan by annealing a white iron of similar composition to the one reported at 1925 degrees Fahr., showed that such a high temperature gives a graphite that looks very much like graphite in gray cast iron.

DR. C. H. LORIG:[3] Last year we published a paper† on the effect of copper in malleable iron in which we gave endurance values. Our results checked very closely with those obtained by Dr. Mahin. I think our endurance ratios were 0.55, 0.54 and 0.50 for the three types of irons tested. I was interested in the type of curve shown by Dr. Mahin in Fig. 2, which is somewhat unusual in the region for the high stress values and low numbers of cycles. Normally curves of this nature do not bend quite so rapidly; instead they slope gradually to a value approaching the tensile strength when the number of cycles approaches zero.

DR. H. A. SCHWARTZ:[4] I was a little surprised at the high endurance ratio that Dr. Mahin obtained, but equally gratified that that should be so, as compared with the work which he quotes, which was done in our laboratory some 12 years ago, and for which a little check work was done by Prof. H. F. Moore at the University of Illinois. I suspect that those check results are not the identical figures that Dr. Mahin obtained from Prof. Moore.

Whether graphite should act as a kind of an intensifier of stress seems, on second thought, to be more doubtful than in the beginning, because in considering nodules of graphite, as far as a three-dimensional system is concerned, you do not have much length of notch, so that even if you intensify the stress close to some nodule, the effect is so extremely local that at a little distance sidewise, perhaps a less effect would be observed.

I suppose that by the unexpected result of the well-known automotive crankshaft made of graphitized cast steel we have a corroboration of a better endurance limit than one would have predicted by just considering the type of material. Of course, there the implication, I believe, has been that in part the lower modulus means that there is a lower stress for a given deflection, which does not enter into Dr. Mahin's contribution to the subject; but perhaps his paper shows us that that interpretation is not the reason why the cast crankshaft is as good as it is. Maybe it actually has the higher endurance ratio that people are looking for.

DR. MAHIN: What Dr. Di Giulio said about the form of the nodules is no doubt correct, but I do think that the important thing is the form of the nodule as a whole. It may be quite compact and approximately spherical, or at least tending in that direction, or it may be branching, as in a photomicrograph he just handed me showing graphite after very high temperature annealing, which does look very much like the graphite of gray iron.

The thing that is important is really the radius of curvature at any given point in the surface of this nodule. Of course when we are talking

† LORIG, C. H., AND SMITH, C. S., *"Effect of Copper in Malleable Iron,"* TRANS. A.F.A., Vol. 42, (1934), PP. 211-226.

[3] Battelle Memorial Institute, Columbus, O.

[4] Manager of Research, National Malleable and Steel Castings Co., Cleveland, O.

about the nodule we are really talking about the cavity, because the nodule has no strength and if the outlines of the cavity are lacking in really sharp projections, then the stress concentration at these points is relatively small.

In that connection, I have always felt that in the usual formulas for expressing the stress concentration at notches, holes, etc., a most important characteristic of such defects has been neglected, no doubt because it cannot very well be considered in a good many cases, and that is the radius of curvature. I spent a little time in puzzling over what one would call the radius of curvature of a theoretically sharp notch. The mathematician says it has no radius of curvature, that you cannot even talk about it, because as a mathematical proposition, the term does not apply; but you can at least use the theory of limits and prove that as a rounded notch becomes more and more sharp, you are approaching a radius of zero, with a theoretical stress concentration of infinity. Of course we know that in the case of metal there is no such thing as a sharp notch, or there can not be after yield begins, so we come merely to the proposition that the sharper the bottom of a notch, the greater the stress concentration.

I am not able to say, through the inspection of this particular photomicrograph (Dr. Di Giulio's) whether there are any projections on the graphite masses that could be called sharp. They appear to be here, but under higher magnification I imagine that we should find that the ends of these cavities are smooth and rounded. This form of graphite is produced, I think, by higher temperature anneal than would be followed in practice. Is that not true?

DR. DI GIULIO : Yes, of course. That iron was annealed at 1800 degrees Fahr. and up, but it happens to be a commercial iron and a commercial cycle.

DR. MAHIN : Mr. Teetor suggested, in correspondence, that we give some comparison of the figures obtained on malleable iron with those of other cast materials. I obtained these figures from the A.F.A. Cast Metals Handbook. I find cast iron given an endurance ratio of 0.39 to 0.58, but 0.58 was exceptionally high—higher than most of the others.

Medium carbon cast steel has an endurance limit of 27,000 to 35,000 lb. per sq. in., with an endurance ratio of 0.40 to 0.50.

Medium manganese cast steel, an endurance limit of 32,000 to 50,000 lb. per sq. in.—and when I give this range, of course, I am merely giving the outside figures quoted from various researches—with an endurance ratio of 0.39 to 0.45.

Medium manganese-vanadium cast steel—the data for which, I believe, was contributed by Mr. Jerome Strauss,—an endurance limit of 52,000 lb. per sq. in. and an endurance ratio of 0.47.

Nickel-chromium cast steel with medium carbon, 1.24 per cent nickel, 0.80 per cent chromium is shown with an endurance ratio of 0.46. No endurance limit is given.

Then, apparently, for the aluminum base alloys, not many figures are on record, unless they have been obtained quite recently. I found, however, that for aluminum-copper alloys, I believe of the heat-treatable, age

hardening type, figures varying from 7,500 to 10,000 lb. per sq. in. for the endurance limit and no endurance ratio given.

With regard to quoting Prof. Moore's figures. I corresponded with Prof. Moore and he stated that he had not published any results but he gave me three results obtained upon isolated specimens. There was no consistency in these figures; you could not come to any conclusion regarding the endurance limit from the figures, and he did not claim that one could. He told me in advance that they were merely some results that had been obtained incidentally. I think two of these values are given here, but there were not enough points for plotting a graph.

Then, with regard to the steepness of a certain part of the graph of Fig. 2, as questioned by Dr. Lorig, this comes about from the fact that the curve is plotted upon a semi-logarithmic scale and this method necessarily makes a steeper portion for high stresses. I do not believe that that slope, or the curvature, is particularly exceptional if you plot upon a semi-logarithmic scale instead of by the use of Cartesian coordinates.

Malleable Furnace Refractories

By L. C. Hewitt,* St. Louis, Mo.

Abstract

A review of rather recent developments in malleable furnace refractories is presented. Bung brick have been improved particularly in respect to resisting spalling action. Comment is made on bung service factors and brick design. Side wall life has been improved through the use of super fire clay brick and high temperature mortar. Tapout block of a super fire clay type have also come into use. Fire brick bottoms laid with cold set high temperature cement are rapidly gaining in favor.

1. A definite advance has been made in recent years in the development of refractories and their application in malleable furnaces.

Bung Brick

2. The improvement in bung brick manufacture has been one of increased refractoriness, greater density for resisting slag action, and a structure that meets to a better degree various types of spalling, namely, structural, thermal, and mechanical.

3. In respect to application, some work has been done toward the idea of using a spring arrangement in the bung head, arranged in such a manner that the brick will be kept tight in the bung and, at the same time, allow for expansion to be taken up without causing pinching action.

4. With the conventional type of bung, the best practice seems to be to tighten the bung thoroughly as it is laid and take up any further slack at each heat after the furnace is up to full temperature. The use of a lubricant, that will not be affected unduly under temperature, such as a small amount of kerosene in the grease used for oiling the bolt heads, aids in keeping them free and workable when subjected to the heat of the furnace.

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* Director of Research, Laclede-Christy Clay Products Co.

Note: This paper was presented at a session on Refractories at the 1935 Convention of A.F.A. in Toronto, Canada.

5. The life of bung brick varies considerably from plant to plant, both in respect to the number of heats and the amount used per ton of metal. The performance ties in with a great many factors, such as laying practice and temperature of operation, distance between the bath and bung roof, width of furnace, bung rise, etc. The situation is such that it is very difficult to correlate service from plant to plant in order to determine fully why there is such a wide variance in the furnace life on the same type of brick. One of the chief destructive forces is the mechanical action to which the bungs are subjected during the charging process. At best, the operation is such that the bung brick edges are often severely damaged.

BUNG REMOVAL PRACTICE

6. In some plants, the practice of removing the charge bungs is to place them over the end furnace bungs, while, in other cases, as they are removed they are placed on the furnace room floor. The latter procedure would seem to be the most favorable, from the standpoint of the charge bungs receiving less mechanical shock and avoiding the heating of the stationary bung frames. The charge bungs, as removed, contain sufficient heat when placed over the frames of other bungs to cause the latter often to get out of shape and to allow the brick in the frame to become loose.

7. The use of an extra taper represents a development in bung brick design. This extra taper is varied to permit of an open joint from 1/16 to 1/8 of an inch to allow for the expansion that takes place in the hot face of the bung brick and thus lessens spalling action due to pinching. The open joint terminates or converges to a point $1\frac{1}{2}$ inches from the brick face. The desirable joint width seems to vary somewhat between plants. Further application will, no doubt, result in a more standardized practice.

8. The idea of laying up this extra or double tapered brick with a dipped joint and then washing or slushing the surface, in order to fill up the purposely formed joints either with regular type of foundry clay or a special high temperature mortar, indicates an advantage. The question may be asked, "Why allow for a joint and then fill it up?" The answer seems to be that the clay or mortar will provide a cushion, as it were, at the joints and also reduce flame cutting action. The use of special high

temperature mortar for laying and washing bung brick in general is also gaining in favor.

Side Wall, End Wall, and Bridge Wall

9. First quality stiff mud fire brick has been the major product used in malleable wall construction. This type of brick has been improved in recent years, particularly in respect to its density and resistance to thermal shock.

10. A type of brick finding application in side walls, front wall, and bridge wall, is that of the super-heat duty fire clay brick class. This type of brick, while not having the mechanical strength that the stiff mud variety has, works out very well in practice, particularly because of the vitreous protection layer that forms in usage. Bricks of the super-heat duty type have a relatively high density, constancy of volume under high temperatures, and high resistance to thermal shock, qualities which, together with refractoriness, account for the generally improved service rendered. With this type of brick, the best practice is to use a special high temperature mortar as recommended by the manufacturer. Sufficient amount of such mortar should be used to fill well all of the joints; in fact, such practice of filling the joints and the use of highly refractory laying mixture should be most economical in most malleable furnaces.

11. The use of super-heat duty fire clay brick in malleable furnace side walls has not, in every instance, proved its value due to differential first cost. Its greatest advantage seems to be in those furnaces that have the most severe operating conditions. Further, plants which are equipped with "stand-by" furnaces and can run a side wall until its full life is completed and do not have to repair every week end, are also better situated for taking advantage of extra heats that brick of this type will produce.

Tap-Out Block

12. Tap-out block, of a specially dense super-heat duty fire clay brick class, are proving of particular advantage in many applications. The life secured is not only longer but the metal stream is better controlled and, in addition, there is the added assurance against the loss of a heat because of tap-out block failure.

MALLEABLE FURNACE BOTTOMS

13. There is a rapidly growing tendency toward the use of fire brick bottoms. This tendency is, no doubt, due principally to the fact that fire brick are now available which do not shrink and allow the metal to enter the joints and float the brick out. The type of brick used has been of the super-heat fire clay brick and 60 per cent alumina classes. While it has not apparently been definitely settled, which one of these two types are the most economical in all cases, it appears that, all factors considered—price differential and life secured—super-heat duty fire clay brick will be standardized for use.

14. The bottom should be laid with a highly refractory cold set cement, in view of the fact that this type of joint will be sealed all the way through and form a monolithic type of construction. The brick are laid on end, that is, the bottom will be 9 inches in thickness. The practice varies in regard to forming an arch, inverted arch, and straight or flat brick bottom. The straight or flat bottom, tied in under the side walls with some space allowed for expansion, would, at this time, appear to be best practice.

(Discussion of this paper will be found beginning on page 59.)

Some Uses of Insulating Fire Brick in Modern Foundry Practice

By C. L. Norton, Jr.,* New York, N. Y.

Abstract

This paper outlines the advantages and disadvantages of insulating fire brick used in the melting of non-ferrous alloys and in the heat treatment of steel castings. The author shows that the installation of insulating refractory brick in non-ferrous foundries has resulted in considerable savings and that in the annealing of steel castings, savings of 30 to 50 per cent have been recorded.

1. Before commenting on the use of insulating fire brick in nonferrous melting and in annealing steel castings, a few general remarks pertaining to this type of refractory might be of interest, since the general use of insulating fire brick is relatively new to industry. Consequently, many people are not entirely familiar with either the advantages or the limitations of this product.

2. Prior to recent developments, "insulating" brick were thought of as a material to back up fire brick to cut down to some extent the heat flow through furnace walls. These lightweight, porous bricks would withstand only very moderate temperatures, but did effect a large fuel saving over the non-insulated fire brick wall. Another type of refractory was a material of approximately one-half the weight of standard fire brick, and capable of withstanding high temperatures. This material, however, did not have the low heat storage and low thermal conductivity of the backing-up type of insulating brick. Neither of these two types of material combined the valuable qualities of low weight and thermal conductivity and ability to withstand high temperatures. More recently, however, material has been placed on the market which does combine to a large degree these properties.

3. When such a material was first introduced as a substitute for heavy refractories, a great many objections were raised

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* The Babcock and Wilcox Co.

Note: This paper was presented at a session on Refractories at the 1935 Convention of A.F.A. in Toronto, Canada.

concerning its actual usefulness. The natural thought to a person accustomed to the use of thick heavy fire brick walls, was that a full sized brick weighing only 2 lb. must of necessity be too frail to give satisfactory service. The most common proof of this by the prospective customer was to rub the material briskly against a hard fire brick or to jab forcibly at it with some sharp pointed instrument. Luckily, this attitude was changed as soon as accurate service records of performance, and what is more important, records of fuel savings began to reach the attention of engineers and furnace builders. In a short time the cold crushing strength, usually determined by the "thumb" method, was given less importance than the more pertinent test of resistance to deformation under load when raised to furnace temperatures. Likewise, the "feel" of the brick, when passed around in table discussions, was given less importance than the more fundamental discussions of thermal conductivity and heat storage.

Several Types Available

4. After the usefulness of this type of material was proved conclusively, a large number of manufacturing concerns devoted much time and energy to produce insulating refractories which would serve the industry to the best advantage. No one product can suitably cover the whole field of insulating refractories, so that several types were produced for various furnace conditions. Insulating fire brick today are chosen for their ability to withstand probable furnace conditions and to render the greatest fuel savings.

Limitations

5. Before passing on to a few specific uses of insulating refractories in practice, it might be well to point out some of their limitations. Insulating fire brick, while displacing fire brick in several types of operation, are not fire brick and cannot always be treated or handled as such. In return for the benefits of better performance, quicker heating up time, and fuel savings, the following items should be considered.

1. Insulating fire brick should not be hammered into place or handled roughly on the floor before installing. A

careless mason may cause the failure of a crown or sidewall by installing or handling in a rough way.

2. At the present time, no insulating fire brick is available which can withstand as high temperatures as the best grade of heavy refractories, and still maintain low weight and thermal conductivity.

3. Due to their porous nature, insulating fire brick will not withstand corrosive slag action unless a suitable facing cement is used.

4. In cases of abrasive action, a hard coating of sufficient thickness must be applied to the exposed face of the insulating fire brick to protect it.

5. A furnace which is cold and empty of a charge should not be brought up to working temperature in the shortest possible time. A somewhat slower start will actually save fuel and will not impose such a heavy spalling strain on the inner face of the wall. Due to the low heat flow through an insulating refractory wall, the inner face comes up to temperature very rapidly, whereas the main portion of the refractory is moderately cool. This results in a shearing action which is more or less destructive, depending upon the flexibility of the insulating fire brick structure. In general, a hard brick will break-up under this spalling action more rapidly than a softer one.

6. For any proposed furnace structure, a material should be selected which is capable of withstanding a higher temperature than that which is actually expected. This allows a reasonable factor of safety, since without it, a few minutes of faulty operation may cause the loss of a complete furnace lining.

An Installation

6. An article by Pritchard* describing non-ferrous melting, discusses the efficiency of brass melting when using an insulating fire brick furnace. In this article, it is shown that the gas consumption per pound of metal melted was less than 3 cu. ft., which is considerably lower than the fuel consumption with a heavy refractory lining. The following personal communication was received by Mr. Pritchard concerning the same installation:

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* May, 1935, Industrial Gas.

a. The reduction in zinc losses due to the shorter melting time actually pays for the cost of the fuel used.

b. The crucible life has been increased.

c. Due to better control of zinc content, metal is more ductile, and rejects from drawing operations are reduced.

d. Due to better grade of metal, tool and die costs have been materially reduced.

7. Another brass melting installation, which is similar to the one described by Pritchard, shows a fuel saving of over 25 per cent when insulating fire brick is substituted for a heavy refractory lining. In addition, the first heat was accomplished in one-half the usual time and subsequent heats were speeded up so that labor and overhead charges on the operation were materially reduced. These last two items are ones which are not usually considered, when an insulating fire brick lining is being figured on, but it can be seen that for any reasonable operation, these items are of considerable importance.

ANNEALING FURNACES

8. In the field of annealing steel castings, it has been found from numerous installations that the fuel savings which are effected from the use of insulating fire brick will be approximately 30 per cent, although in some cases a saving as high as 50 per cent has been recorded.

9. From the above statements it is clear that there are numerous cases where the use of insulating refractories is well warranted and that their use will be more and more universal.

(Discussion of this paper will be found beginning on page 59.)

DISCUSSION

In absence of the authors, Mr. Norton's paper was presented by C. E. Bales, Ironton Fire Brick Co., Ironton, O., and Mr. Hewett's paper by M. A. Hosmer, Hunt-Spiller Mfg. Co., Boston.

CHAIRMAN C. E. BALES:[1] These insulating brick, spoken of in Mr. Norton's paper, are a comparatively new development. There are a great many ways of making these so-called insulating refractories. Some are much better than others; some will stand much higher temperatures than others—but there seems to be a definite use for each class of material.

One process of making the brick is to pulverize the clay, the bulk of which has been calcined at about 2200 degrees Fahr., mix with it a quantity of dolomite, plaster of Paris and sulphuric acid. Then pour this soupy clay into a mold. It is allowed to solidify and is dried, so that all the water is evaporated, and then fired in regular fire brick kilns. After these ingots come out of the kilns, they are sawed into the various sizes, 9-inch brick, 9-inch straights, wedges, arches, etc.

Another process of making this brick is by mixing the clay with naphthalene and then distilling out and collecting this rather expensive hydrocarbon.

The most common method is the mixing of the clay with some combustible material, such as sawdust, wood flour or ground cork or even coke dust and making it into suitable shapes, firing the shape in a kiln and, after firing, dressing them down on a grinding wheel to accurate dimensions. There is such terrific shrinkage in making this type of refractory that they all have to be sized after firing. I do not know of any case where they are able to make the brick without grinding to accurate dimensions, although I think that brick made by the naphthalene process comes quite close to desired dimensions.

There are a wide variety of so-called cellular products on the market now and for some classes of service they are giving wonderful results. Mr. Norton mentions their use for annealing ovens for steel castings and also for non-ferrous melting furnaces. I imagine that last use is for a crucible furnace, because the brick are so porous that if any metal or slag comes in contact with them, it simply ruins them.

DR. J. T. MACKENZIE:[2] We have used these insulating refractories and we accept the makers' data on heat conductivity. The puzzle in the case of lining a forehearth or any holder for iron in a foundry, is how much should you sacrifice to the insulating value for refractoriness?

You are faced with the fact that, in lining the cupola forehearth, if you use 4 in. of refractory brick and 2½ in. of insulation, and with the refractory say melting out at 2900 some day you are going to wear out your fire brick. Now, would it be better to use fire brick that will stand that particular temperature, say 2700 or 2800 degrees Fahr. and lose a little of the insulating value? The only question that has come up in our practice is how much or how thick a layer of insulating brick shall we use?

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[1] Ironton Fire Brick Co., Ironton, O.

[2] American Cast Iron Pipe Co., Birmingham, Ala.

CHAIRMAN BALES: Some refractories, if you insulate them too heavily, wear out in pretty short order. You may be conserving some heat, but you may also be wasting a lot of money on refractory maintenance cost.

THEO. TAFEL:[3] Relative to the use of insulating brick in the forehearth or metal mixing ladle, I had an experience several years ago in Pittsburgh in which we tried to insulate a mixing ladle, using 1 in. insulation. The insulation was so good that the inside fire brick became so hot up to the insulation brick that when the fire brick developed a crack there was no cooling effect whatsoever on the metal and it went right through the insulating lining. We did not seem to be able to figure out any way to prevent that unless we would put a 4-in. fire brick on the outside again to have a cool wall between the insulating brick and the metal lining. Has anyone a solution to this problem?

DR. MACKENZIE: One time we conceived the idea that by insulating the melting zone of a cupola we could get a big saving in coke. We wrapped up the melting zone of this cupola with the result that we completely burned out the refractories in one day. During the first 3 or 4 hours of the heat, we produced wonderful metal temperatures but the refractory cost was too much to pay for the insulating value.

Another thing along the line of the use of granular refractories, at one time we lined up a cupola with about three-quarters to an inch of sand behind the brick, thinking that the silica sand would be a very good refractory and not expensive and might not insulate too much. But about the third heat, the expansion and contraction of the lining broke out all the rivets on the cupola and we were afraid to continue the campaign. All these things have their advantages and disadvantages and you have to take them all into account.

CHAIRMAN BALES: In answering Mr. Tafel's question, I was told how one case of an insulted ladle was handled. In this case they used 1¼ in. of insulating brick, one of these low temperature insulators, and 1¼ in. of fire brick inside that.

MR. TAFEL: We had a good 4½ in. of fire brick. We were afraid of thickening this lining for two reasons: One, that we would reduce our ladle capacity too greatly and two, that even in this case a crack would still leave us in the same predicament, namely hot metal up against the insulation lining, and then again the danger of a run out through our metal shell.

The question, in my mind, seems to hinge on having an insulating method of a monolithic material that of itself is guaranteed against cracking.

J. A. BOWERS:[4] We insulate our forehearth or receiving ladle with 1¼ in. insulating brick but are very careful in putting the 4½ in. of refractory lining inside this. We make the fire clay mortar very thin and lay the refractory brick as close as possible so that we do not have any leak. We did have a leak the first time we put up the ladle and the metal went right through the insulating brick. But, if you make

[3] Standard Sanitary Mfg. Co., Ltd., Toronto, Can.
[4] American Cast Iron Pipe Co., Birmingham, Ala.

your fire clay thin, so that you can bring your firebrick close together, your iron cannot go through $4\frac{1}{2}$ in. if your crack is small, and in that way you can avoid a leak. Once the iron gets through your refractory brick, it is coming out the ladle.

MR. TAFEL: We tried to make the mortar thin and laid the brick up tightly and still the metal came through.

CHAIRMAN BALES: The better masonry work you do, the better service you are going to get. The only other thing that I could think of, Mr. Tafel, is that you probably were using brick which were not entirely suitable for a ladle. Somebody said to me, in talking about a pretty good ladle brick, "Why, according to all tests of the A.S.T.M., that brick is about a fourth quality brick." That is true, it was a poor brick according to A.S.T.M. tests, but for ladle service it was one of the finest bricks on the market.

MR. TAFEL: You would naturally think that a brick that works without insulation will work with it. We tried monolithic linings, too. They worked all right but our heat loss was very high.

DR. MACKENZIE: I think Mr. Bowers did not quite complete the story of our experience. On this first heat we had a runout, but since then we have had 54 nine-hour heats on that ladle, with iron in it at approximately 2750 degrees Fahr. So that the insulating value of the brick has been with us every day, but the poor quality of the masonry was the thing that caused it to break out on the first heat.

Another thing that we have found out is that if we stagger the masonry, we have accomplished a great deal. Do not let the joints of your refractory brick meet the joints in the insulating brick. With staggered brick you have a breaking of the joints, so that the iron, if it once breaks through to the refractory brick, does not also break through the insulating brick.

This brick we used was semi-refractory insulating brick. It was not high insulating brick. We hoped that it would stop the iron if it broke through.

CHAIRMAN BALES: On the subject of insulating refractories, there are a lot of different types of these brick. There are insulating brick that are not supposed to be used as firebrick at all. All they are supposed to do, is back up a regular firebrick lining.

Then there is another class of brick on the market, the insulating refractories that Mr. Norton tells about, that are supposed to be used in furnaces without any backing up, or could be used with backing up but it is not necessary because that type of brick has sufficient insulating power. It is possible to use those brick in furnaces without the protective coating of regular fire brick.

R. H. STONE:[5] I have not run into any crucible furnaces using insulating brick but I have listened with interest at a good many of the open hearth conferences where the matter of insulating refractories has been discussed. From one year to the next, I have watched their increased application and seen it develop fairly rapidly until today, there are a great

[5] Vesuvius Crucible Co., Pittsburgh, Pa.

many open hearth furnaces insulated with insulating brick. They use the semi-refractory, insulating type of brick. And, of course, there they have an intense heat on the other side of the wall, especially where it is used in the roof of the furnace. It has resulted in a great saving of fuel but I believe it has slowed up the operation of the furnaces somewhat, so that they do not get the tonnage for the same time, but they do get a higher tonnage on the same fuel.

CHAIRMAN BALES: On insulating refractories, as I see it, the place where they are of the most value is in heat treating furnaces. You can heat up a charge in the furnace in considerably less time with considerable saving in fuel. Much less fuel is required than if you use a furnace lined with regular fire brick, due to the amount of heat absorbed by regular fire brick and not absorbed by insulating refractories.

In the foundry industry, it looks like insulating brick ought to be very useful in core ovens and in steel and malleable annealing furnaces. Of course, one could not use these insulating refractories in a muffle oven because that would defeat your purpose.

I take it not many of us have used many of these so-called insulating fire brick.

MEMBER: Our melting is all brass and is done in electric furnaces where insulation is extremely important because of the fuel cost, which is probably the biggest cost of the whole melting operation. Of course, you can increase your insulation to considerable thickness and no doubt cut down your melting cost but, as was said before, your inner lining is effected. So you have to find something which fits best in your case.

We found that if we put in brick next to the shell and then put so-called insulating firebrick on top of that and then our refractory material next, that the results proved quite satisfactory. We get fairly good insulation and still we can run our furnace much hotter without damaging our refractories.

CHAIRMAN BALES: That is one place where the insulating fire brick have been valuable. The old type of insulating brick could not have been run up to a very high temperature. Probably 2000 degrees Fahr. was their upper limit. With these insulating fire brick, some can be used up as high as 2700 or 2800 degrees Fahr. and a lot of them at 2500 or 2600 degrees Fahr. In the case of an electric furnace, you would have to use a brick of that type to insulate your refractory material.

A. S. NICHOLS:[6] Most of our experience has been in connection with the insulation of open hearth furnaces, of which we have had experience on some 200 or 250. Some of the fundamental principles which have been followed in that practice may be of interest.

First, we can confine our high temperature insulation practices to the insulation of high load-bearing strength refractories. And, secondly, we insulate to obtain a temperature of some 1700 to 2100 degrees which requires a very careful selection of non-fluxing insulating material.

And, third, we endeavored, in this particular type of furnace, which

[6] Illinois Clay Products Co., Joliet, Ill.

is regenerative, to stress above everything else that the operation of the insulated furnace must take into consideration a compensation in the fuel input for the reduced radiation loss. We attempt to keep the hot faced temperature of the refractories substantially the same as it was before insulation by a reduction of the fuel input. In other words, we would set up a standard input based upon calculated radiation loss reduction beyond which we could not go.

There is only one other thing that comes to mind which I think has a rather general application. In the insulation of this type of furnace, we originally felt the most important thing that we could accomplish would be a very substantial reduction in fuel input and fuel per ton of metal produced. To a certain extent, that was correct. Fuel savings in completely insulated open hearth furnaces ranged from 8 to 30 per cent. That is a rather strong statement in some ways on the 30 per cent end, but in the case of intermitently operated furnaces it is correct. In addition to that, we have found that the elimination of a great temperature differential between the hot and the cold side of the refractory results in a refractory that is more stable than when stresses or strains are set up within the thickness of the refractory by the difference in temperature. In other words, an uninsulated furnace might have a roof with a hot faced temperature of say 2800 degrees Fahr., and the cold side, possibly 12 in. away, would be 600 degrees Fahr., a drop of 2200 degrees Fahr. By placing insulation on that roof we would reduce that temperature drop to possibly only 600 degrees. In doing so, we eliminate plenty of stresses set up there, reduce spalling and, in the case of a certain type of refractory, get a much more resistant type of crystalline structure.

DR. MACKENZIE: One point brought out by Mr. Nichols which I think is especially valuable, is the compressibility of these insulating refractories. While we, in our plant, have not yet had a chance to try it out, we are now lining up an electric furnace with a complete outside ring of insulating refractories which will stand a moderate degree of temperature, say 2600 degrees Fahr., and will take up the expansion of the silica brick. In running an electric furnace very intermittently as we have during the past few years, the main item of cost is the spalling of the refractories due to the number of heatings and coolings. The cost has nothing to do with the tonnage. We could have run 1000 tons with the same refractory cost that we have run 100 tons. I really believe, although I have not had a chance to try it out as yet, that a layer of these insulating refractories, which have a high compressibility, will save us a great deal on this intermittent operation of the electric furnace.

MR. NICHOLS: Relative to this matter of compactibility we had an open hearth experience that might be of interest.

We tried to eliminate or take up the expansion of the roof brick from skewback to skewback by placing 1¼ in. of these compactible insulating refractories behind the skewback in the skewback channel. We thought we would be able to build a roof without expansion joints and stresses transmitted so that the skewback would be pushed against the insulating refractory. The stresses were transmitted in such a manner that the skewback would slide in the channel. In other words, they have to be

within the actual area of expansion or at the ends of straight, horizontal expansion or vertical expansion.

The practice of insulating the furnace wall or cushioning the furnace wall between the expanding brick and the metal binding, metal plate or metal buckstays can be accomplished very easily by laying the walls up tight. Even in existing furnaces that are rebuilt, there is no need to redesign the metal binding. The brick can be laid up tight with no expansion joints, which holds the walls away from the binding, and then compactible brick inserted between the refractory wall and the binding. With expansion the brick compacts, forming a cushion, and no stress is transmitted to the binder.

DR. MACKENZIE: We have been experimenting with insulating material in another way, that is endeavouring to make the work easier on our operators who have to turn the ladle continually 9 hours a day. We insulated one of the ladles with an insulating material in the form of mortar. At the end of 3 hours, we took a thermocouple and found the shell of the ladle to be 300 to 350 degrees cooler than a similar ladle without this insulating material.

D. J. REESE:[7] For a good many years in the malleable industry, it has been considered that the largest ladle that could possibly be used was one of 500-lb. capacity. If one used a larger ladle, by the time it was hauled 300 or 400 feet, the metal would be too cool to pour castings. At a recent foundry conference at Lansing, Mich., one of the malleable men there told of an experiment where they had insulated a trolley ladle and had been able to use one with three times the capacity of that formerly used. So, where the maximum ladle capacity in the malleable industry had been considered at 500 lb., it is now up to 1500 lb.

We have been watching the development of insulating materials, and a good many of the ladles that we make today are insulated ladles. An interesting development that we put out 4 or 5 months ago is a cylindrical type ladle, about 11 ft. long, 54 in. in diameter with 2½ in. of insulation. That ladle acted as a reservoir ladle, holding about 11,000 lb. of metal. We figured the temperature dropped less than 50 degrees. Probably in the future, we will make most of our products in insulated ladles, largely because, with any molten metal, we formerly anticipated a drop of 200 degrees from the time the metal left the spout until it reached the mold, and now, with insulation, that temperature drop can be held to between 50 and 100 degrees.

MR. TAFEL: Do you mind telling us just how you put in this insulation? You said cupola block. Did you ever use monolithic linings?

MR. REESE: Whether the insulating material shall be monolithic or brick depends upon the size of the ladle. On this cylindrical ladle I mentioned, 54 in. in diameter and 11 ft. long, insulating brick was used and then cupola block inside the insulating brick.

DR. MACKENZIE: Perhaps some of the trouble with these insulated refractories is the difficulty of drying out the lining inside of them. The first one we laid up, we ran a lining inside of it and the first time we poured iron into it, the whole thing blew up. The generation of steam was

[7] Whiting Corp., Harvey, Ill.

immediate evidence of the fact that we never had dried it. Since then, we have adopted the practice of putting in the insulating lining, drying that out thoroughly and then using a refractory brick lining inside of it and drying out the whole thing with sufficient temperature that the outside of the shell is very hot to the touch. The metal lining is well ventilated. Has Mr. Reese made any experiments with insulating refractories in Brackelsburg furnaces?

MR. REESE: The first Brackelburg furnace that was brought over to this country was insulated. It was insulated with cinders about 3 in. deep. The monolithic lining was about 24 in. deep. It is possible to take the inner surface of the silica lining above its fusion point and sluff off the inner surface of the lining. The furnaces that we designed, were designed for a 12-in. refractory, the inner 6 in. being silica brick and the outer 6 in. being fireclay brick. Where we get temperatures above the fusion point of silica material, it is necessary for us to radiate heat. We would insulate the furnace as soon as we found that the refractory would take the flame temperatures that we were able to get with pre-heated air. That would be temperatures in the range of 3200 or 3350 degrees Fahr.

We have had a little experience with insulating Brackelsburg furnaces, with the experience to date being on the negative side. The matter of controlling the heat input so that it would be held down to compensate for radiation is something we have not tackled yet although the matter has been discussed with us and with the manufacturers of insulating materials. The heat input in that type of furnace is so high, running around 6 lb. of coal per cu. ft. per hour, around 100,000 B.t.u's. per hour, that it is quite risky to consider it. We have an installation going in at Detroit at this time in which we are insulating one furnace and we will probably have some information on it in the next 6 or 7 weeks.

CHAIRMAN BALES: Mr. Hewitt brings out one thing in his paper with regard to the quality of refractories. He mentions that formerly first quality brick was the type of material that was used in malleable side walls. It has been proved, not only by Hewitt but by others of us, that it is possible to make much better side wall brick than the ordinary first quality product, this super-duty brick he talks about. There are quite a number of those on the market now. Quite a few are made by sizing the various grains of clay and blending those grains together so as to get a fairly dense brick and yet a fairly coarse grained brick. I have not run against many on side wall use, but probably the malleable men can give us some information on that use.

Some time ago we ran across a deposit of clay containing the mineral gibbsite. It is in the form of little balls, and the use of that clay does increase the life of the side wall brick to a considerable degree. I was surprised at the amount of extra service that is obtainable from brick made out of that material.

DR. H. A. SCHWARTZ:[8] Every time I hear anybody discuss malleable refractories, my own impression is how deplorably little we know or learn about them. It seems those who are expert ceramists should, by cooperation with the users of such brick, be able to tell us why one shop does

[8] Manager of Research, National Malleable & Steel Castings Co., Cleveland, O.

remarkably well with a certain brick and another shop can not use it at all, but uses another type brick and swears by it. We also would have the possibility of a very much closer analysis as to why the various parts of a melting furnace fail. Perhaps the foundryman knows something about that and then perhaps the ceramists might suggest the most efficient thing to do about what the foundryman knows.

My guess has been that in the older types of furnaces, most of the side wall failures have been by chemical action. The charge is oxidized and the slag eats up the firebrick. As better means of firing furnaces came into use, pulverized fuel and accurate control of the rate of fuel input and so on, I think the chemical action has grown less and less. Years ago my thought was that, assuming a reasonable refractoriness such as one might have from almost any high grade, first quality firebrick, the next thing needed was the greatest degree of imperviousness possible. The combination of those two made good side walls. I think perhaps the principles are still moderately sound although I think the fire brick people have taken leads of that kind and some others and worked to the desired end.

There seems to be a great deal more argument with respect to bung brick, and I wonder if the answer there is that some people lose their bung brick by spalling and others by high temperature and the two do not go together and therefore plant *A* differs from plant *B* in the matter of bung brick. Naturally, if a man forces a lot of heat through his furnace, he might want a brick which would dissipate heat and keep the surface cool. A man who was not doing that would want one of the less spally types of brick. And on that account we have two types of failure which the foundryman does not differentiate between very well. It is on that account that we have such differences of opinion as to what kind of bung brick foundrymen want and which will wear longest.

CHAIRMAN BALES: Dr. Schwartz brought out one point that I think is highly important on side wall brick. That is that they wear out at the slag line. Several years ago, I analyzed a lot of different slags from malleable furnaces and also secured data on the performance of the brick in those furnaces. We saw that as the iron content in the slag increased, the life of the brick decreased. In those plants the operation was such that they were simply burning up a lot of their iron; this iron oxide was eating out the sidewall brick. In other words, the better the practice in the foundry, the longer life they secured from their refractories in the sidewalls.

J. TRANTIN, JR.:[9] I have had an interesting problem with refractories which probably gave me the idea that the action in, say, open hearth furnaces manufacturing steel, is more or less chemical rather than physical. I tried different types of linings, including fire brick, chrome brick and first and second grade firebrick. During the course of operation, I have had the most successful experiences with the fire brick. In the case of the silica brick, both in the sidewalls and the roof, as well as using chrome brick in sidewalls, there seems to have been a chemical reaction. About the most satisfactory type of lining, both for the sidewalls and the

[9] Youngstown Alloy Casting Corp., Youngstown, O.

roofs, that I have had experience with, has been the firebrick. I have not been able to account for that.

CHAIRMAN BALES: What type of furnace are you using?

MR. TRANTIN: Regenerative type—open hearth. The melting temperature of fire brick is supposed to be about 3100 degrees Fahr., as compared with 3300 degrees Fahr. for the silica brick and the silica brick is absolutely unsatisfactory.

CHAIRMAN BALES: That is strange, since they use silica brick in large open hearths.

MR. TRANTIN: I have tried this experiment, also. I have had a layer of chrome brick and a layer of silica brick and a layer of fire brick and staggered them, and in each case the fire brick stayed in and both the chrome brick and silica brick seemed to have melted.

J. THOMSON:[10] May I ask what size open hearth?

MR. TRANTIN: Small open hearth, about 1000 pounds or less.

MR. THOMSON: In a small open hearth, such as that, maybe the arch was so flat it brought the brick down where they were getting a spray of alkaline slag and that may be the reason.

MR. TRANTIN: I changed the size of the chamber and made it larger and that did not have any effect.

MR. THOMSON: They are subject to the attack of slag, that is the only way I could account for it.

MR. TRANTIN: Unless the type of fuel I was using had some reaction on it. I was using oil.

CHAIRMAN BALES: A lot of fuel oils contain salt.

MR. TRANTIN: This was ordinary crankcase drainings from automobiles.

M. A. HOSMER:[11] We have done quite a bit of work recently on increasing the life of our sidewalls and one of the contributing factors has been, in my opinion, the more careful laying up of brick. We have found that this has been conducive to further life. We do not use any material between the joints at all above the iron line which, of course, enables us to lay the brick closer. There probably are some more expensive materials that you can use that will be as refractory as the brick. The material that we had used previously was not as refractory as the brick and I think that was another contributing cause to shorter life. I might say we are interested in insulation but we have not tried it as yet. I had hoped somebody might say something on that.

As to bung brick, we have had the same experience as Mr. Hewitt, namely, that a great deal of failure has come from mechanical loss, that is, the rough handling of the bung; and that tightening too tight has been a cause of failure of the bung frames. Thus far, I feel that we are not warranted in buying an expensive bung brick. The brick in the air furnace below the iron line seems to give no trouble other than opening up at the

[10] Continental Roll & Steel Foundry Co., East Chicago, Ind.
[11] Hunt-Spiller Mfg. Corp., Boston.

joints, which I think is due to the expansion of the brick after it has been in there for 20 to 30 heats, which causes holes to appear between the brick when the furnace is cold.

CHAIRMAN BALES: Years ago a lot of fire brick used in the sidewalls of a malleable furnace would spall. Fire brick manufacturers have made a lot of improvements. They have gotten to the point where rarely, if ever, do the sidewall bricks spall. They usually fail by slag erosion. In bungs, the principal cause of failure is spalling. There are three kinds of spalling to be recognized, thermal spalling, which is due to a change in temperature; structural spalling, which may be due to a change taking place in the hot face of the brick due to the absorption of the slag, giving it different expansion characteristics from the rest of the brick; and the other method of spalling is pinch or mechanical spalling. The foundryman himself can eliminate this mechanical spalling by having the right type of bung frame. The fire brick manufacturer is making a much better brick from the standpoint of thermal spalling than he ever made before. But we do not know how to overcome the structural spalling because it is difficult to prevent the brick from absorbing vapors, gases and slags.

I have a problem and I would like somebody's help. There is one malleable concern, a large user of refractories, who claims that a brick containing 1½ per cent titania caused them considerable difficulty due to the titania being reduced in the block and coming out as titanium and being absorbed in the castings, which gives them a mottled effect instead of white castings. I have gone into the thing very thoroughly and can not find how it is possible for titanium to be reduced out of fire brick, especially when it is there in such minute quantities. I would like to know whether anyone has ever observed such action as that occuring in his air furnaces or cupolas.

DR. SCHWARTZ: Was there an actual chemical determination of the titanium in the iron?

CHAIRMAN BALES: I asked if the iron had been examined. The foundryman said he could find no titanium. The information he gave me was that the block had 1½ per cent titania, which caused this difficulty, and when they swung back to a block which had a little bit less than 1 per cent, they did not have the trouble. They established anything over 1 per cent titania in the block was the critical point. A block somebody was trying to interest them in ran around 2½ per cent titania. They were afraid to use it on account of their experience with the block that had 1½ per cent titania. Personally, I do not believe it is possible to reduce titanium out of firebrick because as it is melted, the crystals of rutile, will naturally go down and form part of the slag.

A. S. TAIT:[12] We have not had any experience with the titanium trouble in our castings, but we have had some difficulty with a monolithic lining of magnesite and chrome. In melting the first 3 or 4 tons with that lining, we have found as much as 0.3 or 0.4 per cent chrome in our castings, which caused us considerable trouble.

[12] Metallurgist, Dominion Engineering Works, Ltd., Montreal, Canada.

CHAIRMAN BALES: I have heard of cases, too, where people were using a sandstone lining, sandstone spalls or pieces of sandstone, and they claimed they did have a reduction of silica which gave them hard spots in their iron and they noticed it in the machining. Some fire brick contains very minute amounts of zirconium and vanadium. These amounts are so small that you would have to use up several tons of fire brick to get enough in any iron to do any damage.

MR. TAIT: While on the subject of cupola refractories, I would like to bring up another point. We melt a great deal of high test iron, using 75 per cent steel. As you probably know, in the cupola we get a high refractory loss with such a high steel mixture. It has been suggested that the addition of sand with the limestone in the cupola will take care of the silica requirements of the iron and help to prevent attack on the brick. Has anyone had any experience with that?

CHAIRMAN BALES: I have just one point on that question. I have visited a lot of foundries where they melt a good deal of steel and I know that it is much harder on the cupola blocks. I think what happens there is that it takes so much higher temperature to melt down this scrap steel, and probably some of that stuff is oxidized, which forms a very corrosive material to fire brick, and the oxidized steel is what cuts out the lining faster. Now, I have never seen sand added to the cupola but if it was, it would satisfy that iron oxide to some extent and might save the refractories. I do not know how viscous a slag might result. You might have a viscous slag and it might be hard to get it out of the cupola and would probably cause more trouble than ever. Maybe what you ought to have is something which would make a more fluid slag and get it out of the cupola faster.

MR. HOSMER: In connection with the slag line, we are using a mixture of silicon carbide, which is waste material from pulverized old grinding wheels. We mix it with sand and a little clay. It is a cheap mixture and might be of help to some of the members here who have that problem. It does a wonderful job.

In connection with Mr. Hewitt's remark, where he mentioned super-high test fire brick, we have tried those and have had some luck with them. They have worn a little better than our regular fire brick in some instances while in other instances they have not done as well. We have been experimenting with a steam pressed fire brick. Up to this time, we have used almost entirely hand-pressed brick. The steam pressed brick seem to be doing a wonderful job. I think there again it may be due to the fact that they are nearer to size and can be laid more accurately.

We have not done any actual work on insulation but I have looked into the matter to some extent and compared some of the work that has been done. I think there is one thought that I would like to have you bear in mind and that is if you start to insulate a malleable furnace you have to insulate the whole job; you can not do a part of it only. You must keep the furnace temperature on the face of the brick as near as you can to the temperature it was before you insulated it. In other words, you can not expect to insulate the walls and not insulate the bungs. I think when you can insulate a furnace thoroughly you can

keep the temperature down and, as far as I can find out, you should expect minimum loss of brick by insulating the furnace.

A. E. BOCK:[13] We are designing and installing, for our own use, an oil fired revolving furnace for all classes of work, so far as iron is concerned. For the first lining, we have imported a Scotch ganister. Providing the Scotch ganister fails, has anyone any ideas, experience or suggestions as to what we might use for a future lining? Has anyone had any experience or has anyone any suggestions to make with regard to a revolving furnace? The furnace is being operated in conjunction with a recuperator. You have your temperature and slag, and you also have a suspended incandescent arch. The construction of the furnace is a ventilated steel shell. We are using an asbestos insulator, then a 6-in. cupola backing block, and inside that, a monolithic lining. It will be used for all classes of high test and alloy irons.

MR. THOMSON: Has anyone had any experience with the complete building of annealing furnaces with insulating refractories? We have built two annealing furnaces in the past year. They were built completely of insulating refractory. Our experience bears out the statement in the paper that the fuel saving was pretty close to 30 per cent over previous furnaces, constructed with clay brick and in the same structure. It is somewhat of a revolutionary step to build a complete furnace with this material and I was wondering if anyone had any experience longer than ours as to what life we might expect?

CHAIRMAN BALES: You are annealing steel castings?

MR. THOMSON: Alloy steel castings, some of them at rather long cycles, maybe 3 or 4 days. I might also add that in the pit type annealing furnaces for large steel castings, we have experimented over the past 4 years with these refractory insulators in the bungs of these furnaces. These bungs have a span of as much as 16 ft., some 12 ft., some 10 ft., and so far we have gotten away with it all right. There is a little spalling action that takes place but I think that is mechanical more than anything else.

We also have done some experimenting in core ovens. We built core ovens where the walls were built entirely of insulating brick, not this high temperature refractory insulation, but something that will stand about 1600 degrees Fahr. They have been up for about 5 years and still look all right.

Going back further than that, probably 10 or 12 years ago, we put new roofs on brick ovens with a series of sprung arches between I-beams, the arches were built of insulating brick. Some of those arches were put in 10 or 12 years ago and are still there, although the refractory company told me we were crazy when we did it. They had nothing which would prove it would stand up and they did not want us to do it. We tried it anyway and it is still there after 10 years.

It looks to me as though this matter of insulating refractories and insulation has a big future. We have done some experimenting with open hearth furnaces, too, with insulating fire brick. We are not ready to say much about it yet, but it looks as though it was going to be all right.

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[13] Phillip Gies Foundry, Ltd., Kitchener, Ont., Can.

CHAIRMAN BALES: I am glad you brought out the point about that annealing oven because there is one mentioned in the paper. In fact, that is what he recommends this brick for. I think you can reasonably expect you will secure at least as long life from your insulating fire brick as you did from the regular fire brick. There are some peculiarities about some of the insulating refractories that are not completely understood as yet. One is about the spalling action. Some seem to spall quite readily and others seem to be very resistant to spalling. So far, we do not have any test for measuring that.

I might say the Committee on Refractories of the A.S.T.M. does have a special subcommittee on refractory insulation and tests, and definitions are being developed for that new class of brick. I do not believe these brick have been out long enough to tell how long they will last in annealing and heating furnaces.

R. F. HARRINGTON:[14] Do refractory men have any hopes of insulating bungs on air furnaces? Have any of them done it? Is it within the realm of a possibility, or is it impossible as you now view it?

MR. THOMSON: I would like to try and answer part of that question, Mr. Harrington. We would not recommend the insulation of the metal part of the bung made from the type of material which is generally used. The temperature underneath the insulation on your furnaces would probably be about 1800 degrees Fahr. But there is a similar instance in the case of flat suspended arches where the brick are carried by means of hangers and by using high test alloys, of a higher strength and better heat-resisting qualities, they are able to insulate the metal parts. It may be that the use of heat-resisting cast-iron frames would make it possible.

MR. HARRINGTON: One refractory engineer has definitely recommended to us insulation with ½-in. of insulating material between the iron bung frame and the brick and projecting out on the top surface of the brick to within ½ or 1 in. of the end of the brick. In other words, the theory was the melting point of the insulating material was too low, so it could not be carried over to the very edge of the brick. This particular engineer had no hesitancy in recommending to us the use of the insulating material along at least nine-tenths of the top surface of the brick and immediately under the bung frame. We frankly are uncertain as to the possibility and not particularly hopeful.

MEMBER: Mr. Nichols, might I ask you a question? In the case of an air furnace, where you do not have a bung, but just a sprung arch, with a 9-in. roof, would you hesitate to insulate that?

MR. NICHOLS: In the copper and nickel smelting industries there is a type of furnace used known as the Airnod furnace. These furnaces are not regenerative. First one end has to go out, then the other end. Those, as I first saw them, were made of 9 in. of a high-priced clay brick. We insulated the roofs, starting at the stack, the cool end of the furnace, with 2½ in. of insulating brick. When I say insulating brick, I mean not insulating refractory, but material that is more powerful in insulating power. As we approached the hotter end, we narrowed that insulation

[14] Hunt-Spiller Mfg. Corp., Boston, Mass.

down to an inch, using an insulating cement. Since that time, though, those furnaces have been changed over to silica brick roofs with, I understand, much better results. The clay brick roofs worked out satisfactorily, but they are getting long life from silica brick roofs.

MR. TRANTIN: I have a heat treating furnace for steels in which we get temperatures in excess of 1900 degrees Fahr. We insulated this furnace with about 3 in. of mineral wool. My problem was to maintain the temperatures of the furnace for a long time. I manage to keep the heat in so far as the side walls are concerned, but I do lose heat through the roof. Mineral wool seems to insulate the furnace very efficiently, and it seems that my next problem is to put some insulation over the roof, and possibly the application of mineral wool is going to solve the problem further. That was merely an experiment and seemed to work out on the side walls.

L. C. HEWITT (*Written Reply to Discussion*): Dr. Schwartz brings out a very pertinent question pertaining to the variable service obtained on malleable furnace refractories from plant to plant, even in the same brand of brick. As the writer brought out in his paper, "the situation is such that it is very difficult to correlate service from plant to plant in order to determine fully why there is such a wide variance in the furnace life on the same type of brick." As far as I know, no one has been able to definitely correlate the factors involved.

To visiting ceramists, it often appears, in the face of things, that operating conditions in two different plants are very similar and yet the actual life varies widely, particularly in regard to bung brick; and then again, a plant using a certain type of bung brick will report a marked falling off in life and will work around with other brands until they get one that works well again, with the same experience being repeated quite often later on.

While variance in the product as shipped may, no doubt, account for some of these variables, in the main there seems to be no doubt but that the chief variables lie in some phases of operating conditions. The ceramist is handicapped in locating the specific causes for variability in malleable refractory life, in that he is not present to observe all of the various operations from day to day over a long period.

The answer to the question would probably be best obtained through the services of an experienced malleable furnace operator, who would be free to devote his time for a considerable period in close observation in a number of plants. Such a method of attack would, no doubt, be an Association matter. Were it possible to have such a survey of the results gone over with a group of ceramists, some material benefits might be expected.

Mr. Hosmer, in his discussion of side walls, brings out the fact that it is better to lay brick above the metal line without any mortar at all rather than to use an inferior grade and I would agree with his statement. However, I also believe that in most operations it would pay to use a satisfactory type of mortar. If sufficient mortar is used to fill up all voids between the brick and then the brick tamped together, the results

should be such that the excess mortar will be squeezed out and what remains fills up what would otherwise be voids, and thus a tighter structure should be obtained than through the use of no mortar at all. The results depend, of course, on the type of mortar used and the method in which it is applied.

In regard to mechanical loss of bung brick resulting from rough handling, present trend shows that it is possible to produce bung brick of exceedingly high strength and toughness which are yet resistant to thermal shock. Such a type of brick should go a long way toward cutting down mechanical loss, but there is yet to be proved whether or not the increased life would offset the extra cost involved for the production of this type of brick which, in the writer's mind, would be very expensive.

I am very much interested in the comments made by Mr. Hosmer and Mr. Harrington in regard to the possibility of insulating malleable furnace side walls and bungs. Should it be possible, through the reduction of radiation losses, to lower the operating temperatures to the extent that the refractories would not be subjected, in effect, to any greater thermal conditions than they are now, the idea would seem to have considerable merit. It is possible, of course, now to obtain insulating material of the refractory type that will stand up under high temperatures. I can visualize some serious problem, however, in the application of such insulating material to bungs which are under constant handling. The subject is worthy of some considerable study and experimentation.

C. L. NORTON, JR., (*Written Closure*): The discussion was read with considerable interest and the author wishes to thank Chairman Bales for his help in reading the paper and guiding the discussion. Most of this discussion covered the use of insulation on pouring ladles and since we have had little experience with these ladles, there is not much which I can contribute on this subject. I feel, however, that much work could be done on the development of thin walled ladles composed of the refractory facing, backed up with two staggered layers of high temperature insulating refractories. This should eliminate the necessity of preheating the ladles between pours, since the chilling effect on the charge would be reduced materially. It is possible that this type of construction might produce a ladle which would remain tight against leaks and show very good thermal performance.

The fuel savings which were reported on the open-hearth furnaces seem to be in line with our experiences in other types of furnaces. One very important point was brought out by Mr. Nichols when he states that only refractories having high load-bearing strengths can be insulated. This fact seems obvious, but many otherwise useful refractories which have had low load-bearing capacities have failed when used with insulation. This brings up the point that the knowledge of hot load-bearing capacity of furnace refractories is essential for many types of structures.

The most general use of insulating refractories in foundry work lies in annealing ovens. Here, the full advantage of its special properties are made use of. The bricks are exposed directly to the furnace atmosphere and on an intermittent cycle show very substantial fuel savings

due to their low thermal capacity and conductivity. There is a use for these insulating refractories in nearly all intermittent furnaces which are fired with clean fuel, and should be considered as a very light weight firebrick which has, in addition to its refractory qualities, a conductivity so low that thin walls with little or no secondary insulation can be used.

The Influence of Temperature Gradients in the Production of Steel Castings*

By George Batty**, Drexel Hill, Pa.

Abstract

To most practical steel foundrymen the consideration of the effect of metal upon the mold in the act of pouring has been bounded by securing properties in the sand which would make it competent to withstand the erosive effect of metal in transit and, at the same time, be immune from spalling, and that degree of infiltration or penetration by metal which is known as "burning-on." The purely thermal effect of metal in transit upon the mold and the temperature gradients produced in both mold and metal have not been intensively studied in relation to various gating systems or methods. In the following paper the author presents what may, to many, be a new angle of approach to the problem of producing integrally sound steel castings. It appears reasonable to believe that principles of practice that have proved sound in the production of steel castings may be applied also to the production of castings in metals other than steel.

1. In the production of steel castings in sand molds, or in molds formed of other refractory materials, a great deal of attention has been given to the provision of feed heads of adequate size and proper location to promote soundness—freedom from that mid-section cavity known as enclosed pipe—in all parts of the piece. As the complexity of the design increases, and as sharply differential sections are conjoined or relatively heavy masses imposed on a generally lighter structure in positions which are difficult to reach with feed metal, the difficulty in promoting soundness throughout the complete structure generally increases.

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** Consultant on Steel Castings.

NOTE: This paper was discussed at a session on Steel Founding at the 1935 Convention of A.F.A. in Toronto, Canada.

EFFECTS OF RESISTANCE OF THE MOLD TO NORMAL CONTRACTION OF SOLIDIFIED STEEL.

2. The casting of complex design presents additional difficulties which increase the liability to failure, the resistance of the mold to the normal contraction of the solidified metal introducing the tendency to hot tearing or cracking. Despite this fact, it is a common foundry experience to find that among the castings most difficult to produce of a grade that is both commercially satisfactory and free from serious metallurgical deficiencies are pieces which are of harmonious or simple design such as hammer blocks and gear blanks.

3. In part this is due to the relation of area to mass and in part to the system of gating and heading employed. The relation of surface area to mass of cast metal is briefly but illuminatingly commented upon by Briggs and Gezelius[1] who made a series of four pair of castings—each pair being a sphere and a parallelepiped—and determined the rate of skin-formation or actual solidification by turning over the mold after a predetermined time interval and pouring out through the gate the metal which remained liquid.

4. The sphere and the rectangular block were of identical volume but the parallelepiped was of 50 per cent greater surface area than the sphere. The rate of skin formation was found to be almost identical for both sphere and block, but the point of greatest significance to the practical foundryman is that, in the same time intervals, approximately 50 per cent more metal solidified in the mold producing the parallelepiped than in that producing the sphere.

RATE OF FEED DEMAND

5. This set of experiments illustrates quite strikingly what may be defined as "rate of feed demand," which is important to the founder in determining the size and shape of the feed head to be imposed to promote the internal soundness of the casting. The shape or design of a casting must, therefore, have some considerable bearing upon the ultimate cost by reason of the amount of metal necessary to produce the piece and the concomitant cost of cleaning off the discard.

6. It is not necessarily to be assumed that the rate of solid-

[1] Briggs, C. W., and Gezelius, R. A., *"Studies on Solidification and Contraction and Their Relation to the Formation of Hot Tears in Steel Castings."* TRANS. A.F.A. vol. 41, (1933) pp. 385-424.

ification of the parallelepiped will continue to be 50 per cent greater than that of the sphere, but the reported results of the series of tests show strikingly that the distance of the center of the mass from the two nearest opposed mold faces has a profound effect upon the rate of solidification—expressed as a progressive proportion of the weight, not as linear thickness of the continuously thickening solidified envelope—and, therefore, upon the rate of demand for metal from the superimposed feed head.

7. In the case of the sphere the center of the mass of the casting proper is equidistant from every part of the mold-metal interface, which, giving the lowest possible ratio of surface area to mass, predicates the slowest rate of feed demand and, in practice, the greatest amount of metal to be imposed as a feed head to promote soundness of the cast structure. Briggs and Gezelius did not state the dimensions of the rectangular piece used in their experiments for comparison with the sphere, but what they demonstrated in their comparison may also be applied to a consideration of rectangular shapes of different ratios of surface area to mass. Within fairly well defined limits—prescribed by the "castability" of the metal—it is easier to produce commercially satisfactory castings, in relation to internal soundness, as the ratio of surface area to mass increases.

8. The massive casting, say a hammer block, is more difficult to produce free from shrinkage cavity and is more expensive in the amount of metal required, plus the cost of cleaning or fettling, than is a piece of similar weight, say a simple baseplate, having a much larger ratio of surface area to mass.

9. The foregoing discussion has had relation to castings produced by what may be considered orthodox steel foundry practice in relation to gating, heading, and pouring procedure,—gating into the base of the mold cavity; either filling the mold completely, including the feed head, through the downgate or filling the mold proper through the downgate and then filling up the head by pouring directly into it; by using metal as cool as possible, and by filling the mold as quickly as possible. Under such governing conditions it is not possible, even on the simplest forms of castings, to have any pronouncedly favorable temperature gradient in the metal at the moment the mold is filled and, by reason of the gating employed, the mold will have acquired an adverse temperature gradient related in degree to the pouring rate and to the section thickness of the casting.

SECTION THICKNESS IN RELATION TO POURING RATE

10. Section thickness must be considered in relation to pouring rate (rise of metal in mold per second), and it is common foundry practice to insure a high pouring rate for light sections—a cylinder cast vertically for instance. Despite this fact, there is likely to be produced in both mold and casting a distinctly adverse temperature gradient which is inimical to the ultimate integral soundness of the cast structure. The observed fact that the metal which appears in the risers and vents of a bottom-poured casting is very much cooler than the metal delivered to the downgate is such a foundry commonplace, so thoroughly in accord with what is to be expected, that its tremendous significance has not been properly appreciated.

EFFECT OF FEED HEADS ON TEMPERATURE GRADIENTS

11. The obviously adverse temperature gradient in the metal has been noted and feed heads provided of such shape and capacity as to show sound metal when they were cut off and the casting dressed down to the proper size. If the feed heads have to be relatively large in order to promote such apparent soundness and if they are filled through the casting,—as distinct from being filled individually from the open top,—they may help to promote unsoundness in the lower levels of the casting by causing more metal to be passed through the mold, whereby the adverse temperature gradient is increased in both mold and metal.

12. So far as the feed heads themselves are concerned they, being necessarily of considerably heavier section thickness than the part of the casting upon which they are imposed, become reservoirs of heat in proportion as they are reservoirs of metal and so produce, strictly locally, a favorable temperature gradient. Hence, the apparent soundness of the casting immediately below such feed heads. To indicate the relevance of temperature gradients a type of casting has been chosen for discussion which had given some considerable trouble by reason of defects which, while being repairable, were of considerable commercial significance. The casting is fairly simple, is of harmonious design and of almost uniform section thickness. The deficiencies in the casting were all in the lower levels, leaks at the fillets or radiused junction of flange with body, and at bolt holes on the bottom flange.

Orthodox Method of Heading and Gating

13. The orthodox method of heading and gating which was used for the casting under discussion is illustrated in Fig. 1. The mold was placed in a horizontal position on the pouring floor and the casting was poured "flat". It should be noted that the upper ingate (D) is not a true "step-gate" and cannot exercise the devised function of promoting the selective flow of metal from the

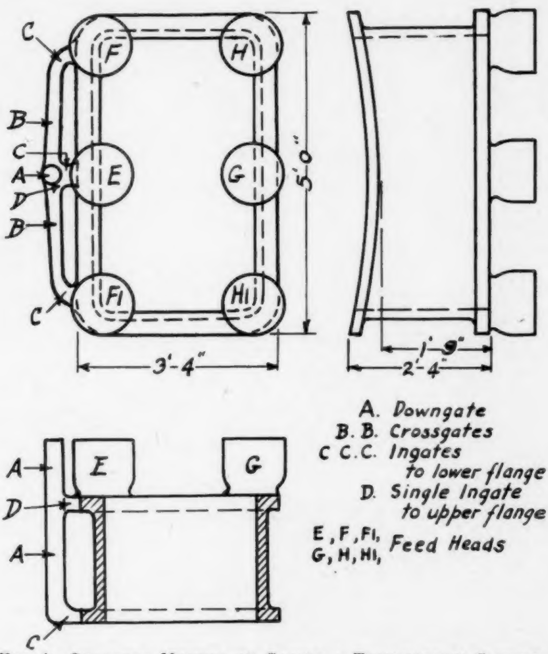

Fig. 1—Orthodox Method of Gating a Troublesome Casting.

downgate into the upper levels of the casting. Without a "breaker gate", devised to check the downward velocity of the cast metal, such an ingate as D cannot reasonably be expected to function properly.

Partial Reversal Method

14. To overcome the deficiencies apparent in the castings made on the orthodox method, such deficiencies being attributable

to the adverse temperature gradients in both mold and metal, and to the local "hot spots" at the lower ingates, promoting the formation of both external tears and mid-section cavity, the "partial reversal" method was used as described in other papers by the author.[2] The method is indicated in Fig. 2 where the casting is

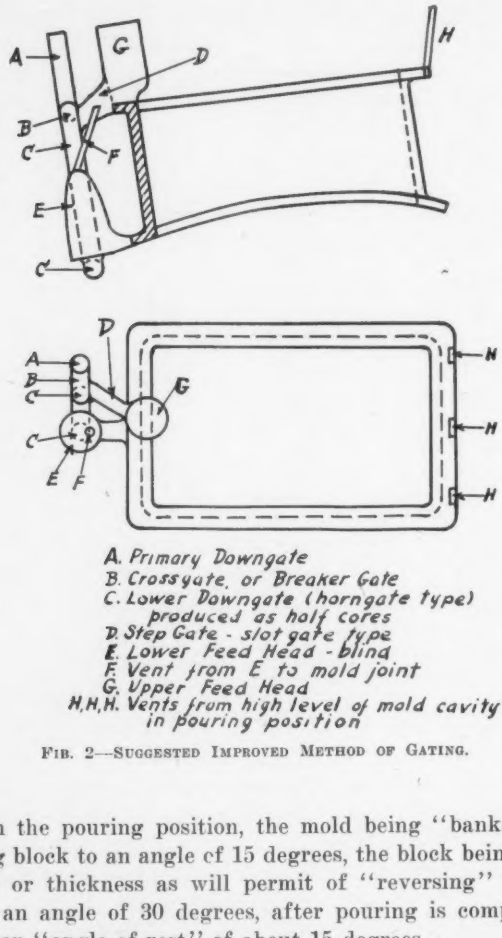

FIG. 2—SUGGESTED IMPROVED METHOD OF GATING.

shown in the pouring position, the mold being "banked" on a reversing block to an angle of 15 degrees, the block being of such a height or thickness as will permit of "reversing" the mold through an angle of 30 degrees, after pouring is completed, to produce an "angle of rest" of about 15 degrees.

[2] Batty, George, *"Controlled Directional Solidification,"* Journal, American Society of Naval Engineers, Feb. and Aug. 1934. Batty, George, *"Controlled Directional Solidification,"* TRANS. A.F.A. vol. 42, (1934) pp. 237-258.

Vents

15. As the gating and heading system, illustrated in Fig. 2, may be somewhat difficult to understand, an additional explanatory diagram is provided in Fig. 3. The vent (F) is taken from the crown of the blind feed head (E) to the mold joint, and the vents (H, H, H) are taken from the mold cavity at locations which are the high plane of the casting proper, in the pouring position. It is essential that these latter vents be adequate to permit the egress of the atmosphere of the mold cavity at such a rate as will avoid developing any serious back pressure which would oppose the inflowing metal; but, in insuring such adequacy

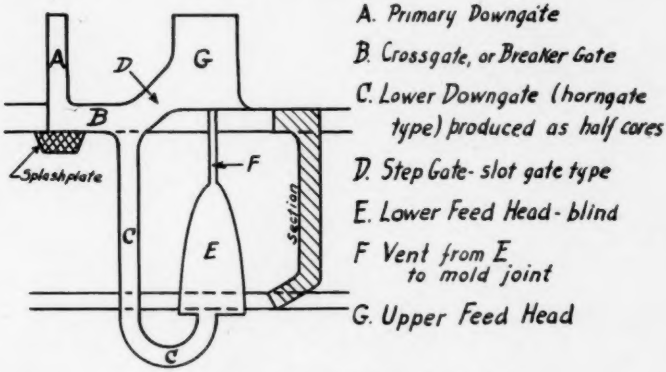

Fig. 3—Explanatory Diagram of Fig. 2.

of aperture, it is necessary to avoid a shape of section which may promote a defect in the casting.

16. Experience has shown that round vents, of sufficient diameter to evacuate the mold atmosphere at a proper rate, will frequently reveal an unsound spot—a fine pipe—in the casting when removed. Vents of rectangular section are greatly to be preferred, and the thickness of such vents should not be greater than one-half the thickness of the section upon which they are imposed. The thickness of the vents being prescribed by the casting, their width has to be determined in relation to the devised pouring rate to insure that serious back pressure by mold atmosphere is not generated during pouring. Vent F is small, and may be of circular cross-section.

COMPARISON OF TWO METHODS

17. A comparison of the two methods of producing the casting illustrated in Figs. 1 and 2 may best be made if we consider vertical sections of the casting, one for each method, comprising

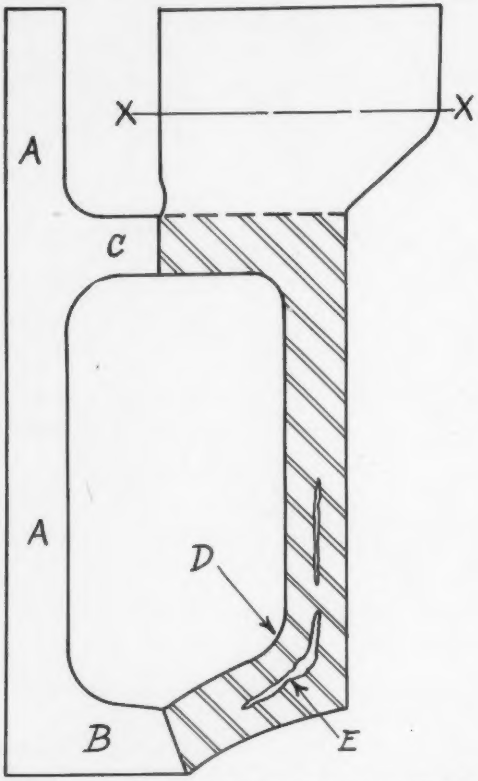

FIG. 4—SHOWING LEVEL OF POURING HEIGHT AND DEFECTS.

gate and head as well as casting. The casting as produced by the orthodox method is shown in Fig. 4.

18. Notwithstanding the provision of the stepgate (C), it is affirmed that the casting, as shown in Fig. 4, would be almost entirely bottom poured, provided that metal temperature and pouring rate were such as to run the casting cleanly, without the formation of serious "cold shuts" or deeply penetrant ripples.

In actual practice, metal was delivered at the downgate until a level was attained approximating the line X-X of Fig. 4. Pouring at the downgate ceased and feed metal was delivered to the head by top pouring directly into the feeder. (Reverting to Fig. 1, and continuing to describe actual practice, it should be stated that riser G was the first to be top-filled, pouring continuing until either the head was filled, or, if metal was flowing to the other risers, until a quantity had been delivered to G approximately equal to twice its capacity. Thereafter, metal was added, in turn, to each riser or feed head until all were filled. As a general rule, however, the metal was so cool at G, H, and H1, that G could be completely top filled without promoting any rise of metal-level in the other feed heads.)

Freezing of an Ingot

19. Most British foundrymen are likely to be acquainted with Brearley's graphic representation of the freezing of an ingot, inscribed lines approximately parallel to the mold faces being used to indicate the progress of the formation of the continuously thickening solid envelope. The casting under discussion, Fig. 4, might be considered as a very poorly designed ingot, parallel sided, and much too great in length—height, as poured—in relation to its diameter or section thickness. Added to this, we have the disadvantages to be associated with bottom pouring. This system of gating could not very well be entirely avoided as the castings were necessarily produced in greens and molds.

Effect of Bottom Gating on Temperature Gradient

20. The bottom-gating of a casting inevitably produces an adverse temperature gradient in the metal, the top of the casting being coolest and the bottom being hottest at the moment the mold proper is filled. The amount of this temperature difference, and the "angle" of the temperature gradient, are related to the pouring rate—rise of metal in mold per second—and to the heat-conductivity of the mold. A slow pouring rate will produce a poor temperature gradient, as compared with that produced by fast pouring, when the gradient is indicated in the manner illustrated on Fig. 5. As the gradient line more closely approaches the vertical, for bottom poured castings, the more favorable are the conditions for producing soundness by superimposed feed heads.

METAL TEMPERATURES AT DIFFERENT LEVELS OF CASTING

21. It is not suggested that the gradient lines shown on Fig. 5 accurately represent the metal temperature at the different levels of the casting, but the diagram is used—as the author has used it in discussions with operative foundrymen—to indicate the general trend of one effect of bottom pouring.

22. The transfer of heat from the metal to the mold is the prime reason for the notable difference in temperature existent between the upper and the lower metal in the mold and it is

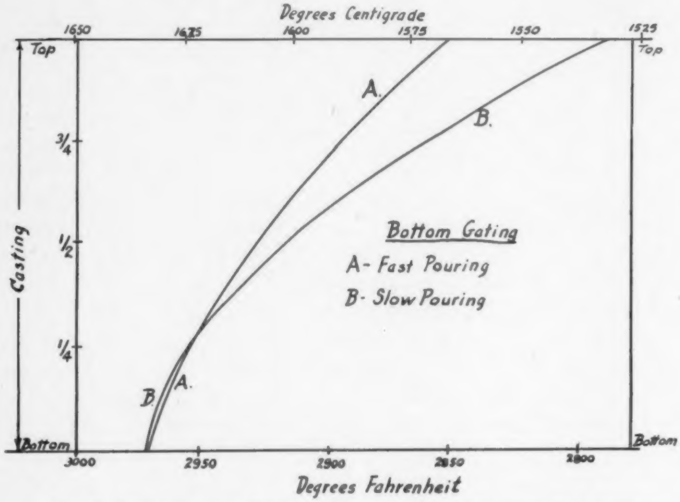

FIG. 5—INFLUENCE OF BOTTOM GATING ON TEMPERATURE GRADIENT.

reasonable to believe that such transference of heat is, to some considerable degree, related to the duration of contact of metal with mold in the act of pouring. It therefore follows that the lower levels of the mold, closely adjacent to the ingate, are considerably heated and delay the solidification of the metal. Hot spots, so generated, produced two types of defects in the casting (Fig. 4) under survey:

a. External hot tears at the radius D, and
b. Internal shrinkage cavities E.

23. All the castings of this type, produced on orthodox methods, (Fig. 1) showed these defects at each of the three lower ingates and while external chilling at the radius eliminated or

decreased the incidence of external hot tears, the mid-section unsoundness persisted. Failure to deliver feed metal to the affected parts is believed to be a considerable factor in the combination of causes which promoted the defects.

24. In the revised system of production the castings were gated and headed, and were poured on what is called the "partial reversal" method, as indicated on Fig. 2. It should be noted this method prescribes, as essential to its efficiency, that the castings be preferably gated and headed at one end of the long axis, whereas the castings produced on the orthodox method were gated at the side, or parallel with the long axis. Green sand procedure had to be followed and the casting was, necessarily, bottom gated to provide for the introduction of the metal in a quiet, non-turbulent manner.

HORN GATING

25. Horn-gating into the bottom of a side, or elbow, riser has distinct advantages over either the straight or the tangential ingate. In the particular case under discussion it had the added advantage of overcoming one of the deficiencies of the ordinary blind riser in that the "geyser" effect of the ingate almost entirely prevented the accumulation of relatively cool metal within the blind head.

26. The angle of pouring prescribed that at least two-thirds of the casting would be produced by metal flowing through the lower ingate and the speed of pouring was steadily accelerated until it could be seen that metal was flowing through the upper gate. It is believed that, with the indicated gating system, metal ceases to flow through the lower gate almost immediately upon the commencement of delivery through the upper gate, and it therefore follows that the lower levels of metal quickly come to rest and can proceed with solidification while the upper levels of the mold are being filled.

AVOIDANCE OF COLD SHUTS OR RIPPLES

27. The pouring rate must be such, as in the case of the castings made on ordinary methods, that serious "cold shuts" or ripples are avoided.

28. On Fig. 6 is indicated the gating and heading system used on the "partial reversal" method. In comparing this with Fig. 4 it must be remembered that Fig. 6 shows the whole of the

heading system whereas Fig. 4 showed only one of the six risers. The two feed heads used on the partial reversal method weighed a little less than half the total amount of head-metal used on the ordinary method.

29. The actual gate-aperture at the lower flange, as shown on Fig. 6 was 9 ins. x 1¾ ins. which insured the entry of the metal into the mold proper without serious turbulence. The blind head, disposed immediately above the horn type ingate, functioned as a balancer to avoid surging within the mold cavity. In visualizing the flow of metal in the mold—remembering that the mold is

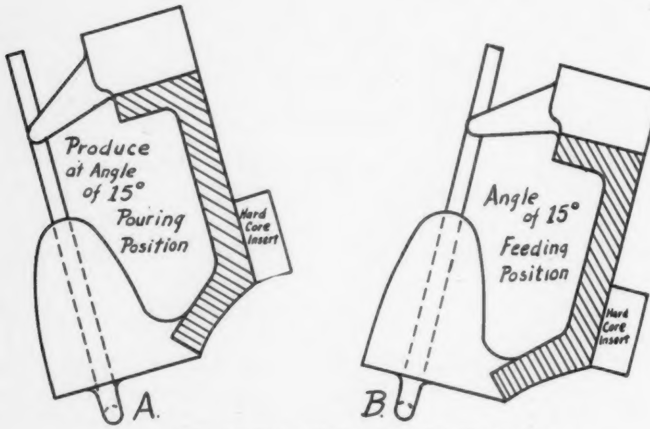

FIG. 6—THE PARTIAL REVERSAL SYSTEM OF CASTING.

inclined at an angle of 15 degrees, the ingate being the low point—it can readily be seen that distribution from a single large ingate must produce practically identical temperature gradients in the lower levels of the casting on each side of the long axis. Vertically, there is a local adverse temperature gradient for approximately two-thirds of the height of the body end wall adjacent to the gating and heading system; but, as the upper gate begins to function this adverse temperature gradient in both metal and mold does not become acute.

DELIVERY OF METAL

30. Approximately one-third of the metal which forms the casting is delivered through the upper gate, the metal delivered

by the lower gate tending to build up to an appreciable "head" within the mold above the lower ingate and balancing the pressure at the downgate. Without the "breaker" gate, the upper gate would be late in functioning and a considerably more acute adverse temperature gradient would be produced adjacent to, and above, the lower ingate.

31. The upper ingate is definitely a "slot" and is inclined upwards to ensure a mild whirling or eddying motion of metal within the riser. This device is calculated to prevent the formation of a cool upper layer of metal within the riser as the upper levels of the casting are poured. If an ordinary flat ingate is used at the base of the upper head it is found that very little eddying occurs in the riser while the upper levels of the mold are being filled. Consequently, when both mold and riser are filled—the top of the riser, in the case under discussion, being several inches higher than the high point of the casting at the other end of the mold—there may be several inches of relatively cool metal at the top of the riser, lying over the hotter metal in the lower part of the riser. This is a local adverse temperature gradient which can be avoided by using a slot gate.

32. The vents will seal themselves if they are of proper number, size and shape, and the mold may be "reversed" as soon as the ladle moves away. The mold is located approximately in balance on the rocking blocks or bar and, the wedges being removed, may be reversed through an angle of about 30 degrees to produce an angle of rest of 15 degrees. Molds of considerable size may be manipulated, but the larger molds, containing castings weighing upwards of 3000 pounds usually demand the services of a crane.

33. At the "angle of rest" the casting is in the "feeding" position where gravitation may amplify the effect of whatever favorable temperature gradient has been produced in pouring and reversing the angle of the mold. The adverse temperature gradient in the lower levels of the section shown on Fig. 6 is taken care of by the blind riser, which is placed in a superior position by the reversal of the mold, and by the favorable temperature gradient of the upper levels of the casting plus the superimposed feed head.

34. This casting, taken as an example for discussion at such length and in such detail, is not one which presents potentialities for the production of a perfect temperature gradient in both mold

and metal, but it does present an opportunity for the citation of the successful application of the temperature gradient theory whereby controlled directional solidification was attained and commercially sound castings produced in a foundry which theretofore had experienced some considerable trouble and loss in making such pieces.

35. It might be argued that if the heading and gating system used on the partial reversal method had been employed along with orthodox "pouring on the flat", the temperature gradients requisite to the production of a sound structure would have been secured without the trouble of "reversing" the mold. Such an argument seems cogent, but it can here be stated that the argument was advanced and the method tried. It was not entirely successful, and it was demonstrated that without the reversal method larger feed heads were required. Even with these larger heads the body wall section adjacent to, and above, the lower ingate was not as sound as when the reversal method was used.

TOTAL REVERSAL METHOD

36. In steel foundry practice the most favorable temperature gradient in both metal and mold may be attained by a system of operation that has been called "the total reversal method." Within limitations prescribed by the available equipment this method is productive of very definite economies, on certain types of castings, and at the same time promotes a degree of integral soundness of structure unattainable by ordinary methods.

37. The example chosen for description is a liner of the design shown by Fig. 7. Normally, such a casting—which has to be machined all over and must also be of uniform internal soundness—would have to be made pronouncedly tapered in section, tapering from heavy section at the top to light section at the bottom. Such a provision would, in turn, demand additional expense in machining off the excess metal.

38. The casting, as shown in Fig. 7, is a hollow cylinder having almost uniform wall thickness from collar to end. The feed head is annular in form and the gating system is produced in two cores. The upper core, in the pouring position, provides ten ingates while the lower core contains the annular distributor gate which is connected to the base of the downgate by a double cross gate. The downgate is either tile (stopper sleeves may be

used) or is made of special cores. A solid pattern, with feed head pattern and the print for the gate cores firmly attached, makes practicable the very simple one-part molding method.

39. After the pattern is drawn, the mold cleaned, center core inserted and the gate cores positioned—these acting as centralizing cores for the center core—a base plate is firmly clamped on and the mold turned over into the pouring position as

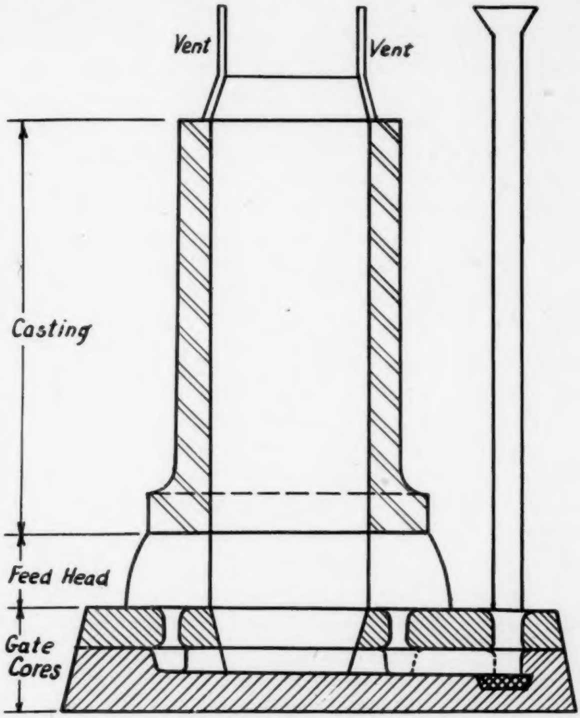

FIG. 7—LINER CASTING LENDING ITSELF TO THE TOTAL REVERSAL METHOD.

shown by Fig. 7. As the mold is to be completely reversed after pouring it is necessary to affix a cover plate or board. This must be provided with holes or slots to allow free venting of the mold atmosphere.

POURING OPERATION

40. The pouring operation—predicated by experience—applies metal as hot as practicable and a pouring rate as slow as

practicable. These provisions produce in metal and mold the greatest practicable temperature gradient which, after the mold is reversed through an angle of 180 degrees, bringing the head into its proper position to deliver feed metal, presents a metallurgical picture akin to that of a tapered ingot—big end up—in a well designed ingot mold provided with a hot-top or brick head.

REVERSAL AFTER POURING

41. With the casting in the reversed position after pouring, the lower levels of the metal are cool and are in contact with cool

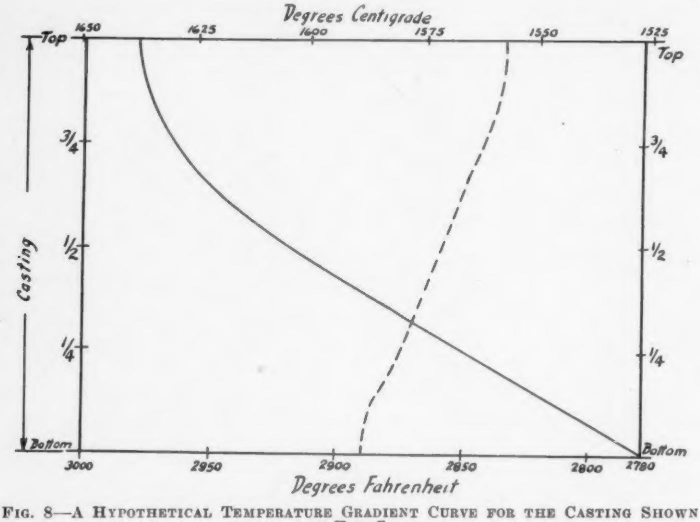

FIG. 8—A HYPOTHETICAL TEMPERATURE GRADIENT CURVE FOR THE CASTING SHOWN IN FIG. 7.

mold while the upper levels, particularly in the head, will be maintained in a fluid condition for a considerable length of time by reason of the heat of the mold with which they are in contact. In constructing a diagram to indicate the progress of solidification for such a casting in such a mold, using Brearley's method of inscribed lines, the lines would not be drawn parallel with the mold faces but would, rather, incline toward each other as in an elongated V.

42. Fig. 8 presents as a full line a hypothetical temperature gradient for the example under discussion, the line sloping down-

wards from left to right, such inclination being indicative of substantial feeding potentiality by the superimposed "riser". The broken line on the same figure is a hypothetical temperature gradient for the same casting bottom gated at the light section, with the collar or flange and the feed head at the top. In attempting to produce such a casting in such a manner it is to be assumed that a fairly rapid pouring rate would be ensured and that the metal temperature would not be unduly high.

43. Admittedly Fig. 8 is conjectural, but the suggested gradients are based upon observation of the pouring of many castings and the examination of a number of castings which have been "bled", either intentionally or fortuitously. In scrutinizing the temperature gradients it is not to be assumed that anything but an average for the section is intended to be expressed. It is recognized that a temperature gradient exists from surface to midsection and, in a horizontal direction, from gate to parts remote from the gate in castings which are poured "on the flat".

TEMPERATURE GRADIENT OF MOLD

44. The temperature gradient of the mold—really a relatively thin envelope of mold surrounding the casting—is much more difficult to visualize. Briggs and Gezelius[3] have shown that throughout a considerable part of the cooling of a cast 6 in. diameter sphere the temperature of the sand at a distance of one-eighth inch from the mold-metal interface was only about 150 degrees F. less than the temperature at the centre of the sphere. Despite the low thermal conductivity of sand, the mold takes a considerable amount of heat from the metal in transit, as is demonstrated by castings accidentally "bled" as the result of a break-out near the gate. Such remanent shells show an envelope of considerably greater thickness formed at the upper levels than at the lower levels close to the ingate, and demonstrate the potency of the mold as a coolant in relation to pouring temperature, pouring rate and section thickness.

45. It is obvious that the potency of the mold as a cooling agent decreases sharply as section thickness increases but the potency of the mold increases as the distance to be traversed by metal within the mold increases. Thus, the temperature gradient which can be created in a cast 6 in. cube, suitably headed, is very slight as compared with that attainable in a cast piece 6 in. x 6 in.

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[3] Briggs and Gezelius, TRANS. A.F.A., vol. 41 (1933), pp. 385-424.

x 72 in. long produced on the partial reversal method. (For detailed descriptions of various mold manipulative methods, partial and total reversal, the auditor or reader is referred to previously published papers by the author.[4]

AMERICAN AND EUROPEAN PRACTICE

46. In discussing temperature gradients the author has adhered to examples of castings made under conditions which largely govern American practice. In this country little, or no, molding material is used that has the characteristics of either the British "compo" or the Continental European "chamotte", and it is fairly general practice to gate into the lower levels of the mold. Top-pouring such as may be adopted with "compo" molds is relatively rarely used in American foundries.

47. The temperature gradients in mold and metal which may be created by top pouring are more favorable than those attainable by bottom gating unmanipulated molds, but are not as favorable as those to be achieved by bottom gating and "reversing" the mold after pouring is completed. A fine example of good gating method is provided in Hatfield's paper[5] delivered to the American Foundrymen's Association Convention in 1934. The heading of the casting is also very interesting as it shows an appreciation of the necessity for a large volume of feed metal when blind risers are used which are not directly served by ingates. The filling of such risers produces in them—as it does in ordinary open heads which are not filled from the top—an adverse temperature gradient in both mold and metal. It is, therefore, necessary to have risers of such dimensions, in relation to the sections with which they are connected, that their reserve of temperature is adequate to maintain fluidity of their interior metal over a period of time sufficient to ensure the solidification of the casting; or, at least, of that part of the casting which each riser is devised to feed.

TEMPERATURE GRADIENTS IN BOTTOM GATED CASTINGS

48. The temperature gradients in a bottom gated casting are bound to be adverse, and only a locally favorable condition can be created by top-filling the feed heads. Reverting to the part of a casting shown on Fig. 4 and including the feed head, a

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[4] Geo. Batty, TRANS. A.F.A., vol. 42 (1934), pp. 237, 258. Journal, American Society of Naval Engineers, Feb. 1934 and Aug. 1934.

[5] W. H. Hatfield, *"Steel Castings,"* TRANS. A.F.A., vol. 42, (1934) pp. 672,694.

temperature gradient of the type postulated in Fig. 9 would probably be produced a short time after pouring was completed. The local favorable temperature gradient within the feed head will ensure that the casting proper immediately below the riser will appear sound when the head is removed, but the adverse nature of the temperature gradient for the lower three-quarters of the height of the casting—amplified by the adverse temperature gradient of the mold, resultant upon bottom-gating—points to the conclusion that the casting cannot be expected to be free

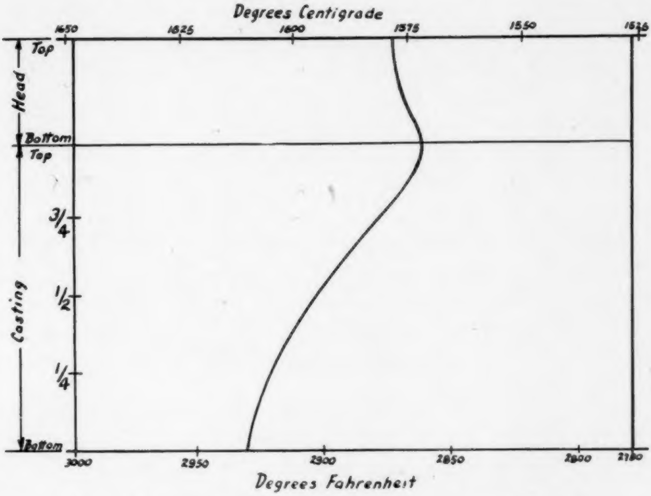

FIG. 9—TEMPERATURE GRADIENT IMMEDIATELY AFTER CASTING.

from mid-section unsoundness in the lower levels. Thus it must be realized that design is a factor of very great importance and that for castings produced in unmanipulatable molds—molds that cannot be "reversed" after pouring—the taper or "wedge" type of section, small end down, should merit the attention of designers as being complementary to the production of integrally sound cast structures.

TAPERING WALL SECTIONS

49. In castings which are of a size that can be produced in manipulated molds—using one of the reversal systems—there

does not exist to the same extent the necessity for tapering wall sections, the creation of favorable temperature gradients in both mold and metal being competent to overcome, to some considerable extent, the normal difficulty of feeding a section. There is, however, very definitely a limit to what can be done by mold manipulation, this limit being prescribed by practicable pouring temperature and pouring rate.

CONTROLLED DIRECTIONAL SOLIDIFICATION

50. One of the features of promoting controlled directional solidification, as the result of properly organized temperature gradients, which appeals to the steel founder is the economy of feed metal. It is admitted that the discovery of the extent to which this economy could be carried was accidental—but for the accident, unnecessarily large feed heads might have been continued in use—and that the early applications of mold reversal were successful attempts to cure defects which were apparent in certain castings immediately the risers were removed. The temperature gradient theory is built upon the practical results arrived at by manipulating molds after pouring is completed and is applicable with beneficial results to castings made in molds that cannot be so handled as it leads the practical foundryman to a more correct appreciation of the functions of gates and heads.

51. A system of step-gating may be considered as being of less efficiency than mold reversal, but more efficient than bottom gating, in promoting soundness of cast structure.

PERFECT PROGRESSIVE SOLIDIFICATION

52. The concept of perfect progressive solidification, from bottom to top in orderly continuity, is one that must be discarded because of its utter impracticability; but controlled directional solidification is, for cetrain types of castings, an implement available to the founder. The means described[6] for achieving the desirable condition by "reversing" molds or by a good system of gating and heading must be amplified by "chilling" isolated masses, pads, or bosses that cannot conveniently be reached by feed metal. For reasons which are apparent to most practical steel foundrymen the writer disapproves the use

[6] Geo. Batty, Journal American Society of Naval Engineers, Feb. and Aug. 1934, and TRANS. A.F.A., vol. 42, (1934) pp. 237-258.

of internal chills—variously described also as residual, cast in, remanent—in locations which can effectually be treated by external chills. It is conceded that in some instances an external chill cannot be used and that nothing but an internal chill will achieve the desired result.

EXTERNAL CHILLS

53. In promoting controlled directional solidification external chills can be made to function efficiently upon parts that could never be adequately dealt with by internal chills, and this without the dangers of blows and the inhomogeneities resultant upon the use of cast in denseners. The designing, as to shape and weight, of external chills in relation to the parts upon which they are imposed is an infant art but is one which will be developed to the benefit of both castings and founders. The shape of the chill must be such that it will not promote a sharp line of chill effect. It should be devised to take care of that excess of cast metal which is imposed on the general structure as a boss or pad without interfering with the whole projected scheme of solidification. If the chill is excessive in its effect, it may tend to negative other means taken to insure an ordered and progressive solidification by closing the avenue through which feed metal should reach other parts of the casting.

54. The weight of the external chill must be related to the amount of heat it may have to take up from "metal in transit" as well as to the amount of heat it is devised to take from the "metal at rest" when the mold is full. It seems probable that the designing of efficient external chills will be arrived at empirically and will be an art for some considerable time before sufficient fundamental knowledge is amassed to warrant precise scientific definition.

55. While chilling may be used to mitigate the dangers attendant upon concentrations of metal which cannot be fed from risers the fact remains that the designer can, if willing, do much to eliminate the necessity for such costly foundry expedients. Heuvers[7] has suggested variations from orthodox practice in design which make a distinct appeal to the steel founder, but it must be remembered that some inescapable features of design tend to create "hot spots," which, in turn, tend to promote either internal cavities or externally visible tears, or both.

[7] A. Heuvers, *"Was hat der Stahlgeber dem Konstrukteur über Lunker—und Ribbildung zu sagen,"* Stahl und Eisen, No. 35, 1929.

FILLETS, GATES AND HOT SPOTS

56. The founder rightly insists upon radiused junctions where two sections of metal would, otherwise, produce sharp corners or angles of sand projecting into the metal. The imposition of the fillet produces a local concentration of metal that must either be fed or chilled to insure complete soundness. Internal hot tears or enclosed pipe are evidence that "humps" have occurred in the temperature gradient—if it was generally of a favorable type,—or that the temperature gradient was generally of an unfavorable nature.

57. "Hot spots" are most likely to form at the ingate. Simple modifications of gate design appear, superfically, to cure the trouble but it must be said that in many cases the "Cure" is more apparent than real. The casting merely appears to be sound on the surface when the gate is removed, yet there may be a mid-section unsoundness. Such a localized deficiency may be a commercial defect in certain types of castings while in others it is a metallurgical defect of no serious commercial significance.

58. On many types of castings, poured in the orthodox way, it is easy to locate the hot spot outside the casting by gating into a main riser. Valve bodies and flanged fittings have a pronounced tendency to exhibit leaks either at the radiused junction of flange and body or at a bolthole when gated at the edge of a flange. This bespeaks, of course, a crack or tear which extends to the bore of the casting. Such a tear or crack is due to a gate hot spot, and the trouble can readily be cured by gating into the base of a lumped riser—sometimes called a face riser or elbow head—on the face of the flange. Such a riser should be at least twice as thick as the flange upon which it is imposed in order that the centre of the mass—the last to solidify —is outside the casting. This procedure may necessitate longer coreprints than are normally provided, but the small expense of alteration to pattern and corebox is generally a good investment.

INTERNAL CORNERS AND TEARS

59. The tendency of box-like cast structures to tear at the corners is well known, and this tendency persists even though the metal section is uniform, the external contour paralleling the internal radius. In such an example is demonstrated the effect of disproportion of metal to sand. The corner or "angle" of

sand, even though apparently suitably radiused, is heated on two sides; it is subject to nearly twice the thermal attack that is imposed on the sand forming plain faces and it cannot take heat from the metal at the same rate as does the sand in contact with plain plates of metal.

60. Every so-called internal angle is, therefore, potentially a hot spot. These local humps in the general temperature gradient may generally be avoided by face-nailing the fillets, but a nice discrimination is necessary in prescribing the amount of such chilling. By "face nailing" is meant the use of short, flat headed nails inserted until the heads are flush with the mold face. The heads do not project into the casting to become, thereby, internal chills. The application of this simple remedy is not always practicable because of pattern construction.

EFFECT OF THE MOLD TEMPERATURE

Thus far, the author has treated the subject in relation to the influence of gating and heading methods, together with mold-manipulation, in promoting soundness in the cast structure which, in other words, is freedom from external tears and internal shrinkage cavities. It appears desirable to emphasize the effect of the mold—which is affected by metal in transit—upon the progress of solidification of the casting because the literature pertaining to the production of steel castings has, hitherto, hardly touched upon the matter.

61. The extent of this effect is demonstrated by castings produced on one of the reversal methods where, by mold manipulation, the temperature gradients of both mold and metal are disposed in the correct direction.

62. At temperatures above the liquidus, steel is believed to behave as a true liquid, and McCance[8] gives the figure 0.00039 contraction per degree Cent. It therefore follows that if those mold parts which are ultimately to become the upper levels of the mold can be considerably heated by the relatively slow pouring of hot metal at a rate which, while sufficient to insure a cleanly run casting, cools to a considerable extent an appreciable amount of the metal, the mold is made to conserve heat in a graduated manner and control, directionally, the solidification of the casting.

63. Such conservation of temperature, particularly in the

[8] A. McCance, Foundry Trade Journal, Dec. 27, 1928.

heads of totally reversed castings, will, despite the high temperature of the upper levels of metal, result in adequate feeding from a relatively small reservoir or feed head. Cases have been noted where risers delivered as much as 35 per cent of their volume to the casting, this being approximately equal to 3.5 per cent of the volume of the total metal in mold. This figure of 3.5 per cent is somewhat higher than the average contraction, measurable as pipe, in castings examined by the writer. To state the matter in another way, certain castings have been produced, ranging in weight from 200 to 1000 pounds, with a discard of only 6.5 per cent. Admittedly these castings were made on the total reversal method, and every precaution was taken to promote conditions that would give a high yield, yet it may be said that castings of a similar type and larger in size were consistently made on the partial reversal method with an average yield of over 85 per cent of metal in mold.

64. The temperature gradients in castings at temperatures below solidification point must be a study separate from the matters discussed in the foregoing part of this note. Cold cracking is probably more to be associated with design than with molding and pouring procedure. This statement is made because some designs have been noted which consistently developed such stresses in the castings as to lead to a considerable proportion of loss by cold cracking, but only small losses by hot tearing.

65. Fig. 10-A indicates the design of a truck wheel which was common a number of years ago, in the era of the solid rubber tyre. Fig. 10-B shows the modification of spoke design which overcame the trouble of cold cracking of the spokes. It should be noted that the only modification was the alteration of the shape of the spokes, the hub and rim remaining the same in both designs. The spokes, six in number, are of cruciform section, Y type, and split to give twelve junctures with the rim and midweb. In the straight Y type, Fig. 10-A, these junctures were equally spaced. In the curved Y type (Fig. 10-B) the distance across the top of the Y was slightly greater than the distance between the tips of two Y's.

66. The wheels were gated at the hub, thus insuring that the casting was gated into its heaviest section, and also that distortion was reduced to a minimum by providing that the metal at any two or more parts of the castings equidistant from

the center be of the same temperature, or as nearly so as possible, at the moment the mold is filled. This provision seems necessary on such castings as truck wheels which are of light general section and which must be as nearly as possible in balance after machining. It is not so important on heavier castings such as gear blanks.

67. The chief trouble experienced in the production of the wheels having the straight Y type spokes was a pronounced tendency to cold cracking either at the points marked *X* or at *A* (Fig. 10-A). Relatively few of the castings failed by reason of

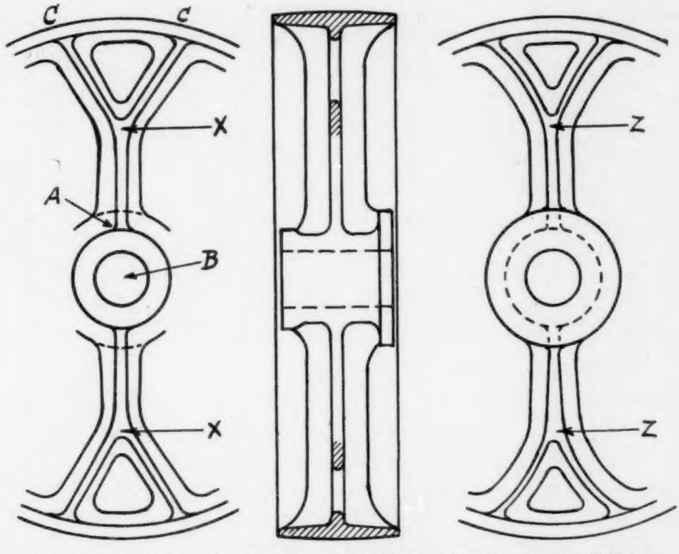

Fig. 10—*A* (Left), *B* (Right)—Lorry-Wheel Design of the Y-Type.

hot tears at these locations, and the magnitude of the residual stresses obviously varied in different castings. Some would cold-crack during cleaning operations and the practice of heat treating—a straight normalizing—before fettling did not entirely eliminate the trouble. As a matter of fact, a number of fully machined castings were known to develop the characteristic crack in transit, by rail, from foundry to customer.

68. It is believed, by the writer, that the tendency to crack was increased by machining, the removal of metal from the face

of the tread and from the bore adversely affecting the residual stresses which, previous to machining, were not so remote from equilibrium as to promote a crack. This detail will not be discussed at length in the present paper.

69. A scrutiny of the defective castings showed that in an overwhelming majority of the examples, a crack occurred at or near a point of metal concentration. Any deviation from the practice of gating at the hub aggravated the trouble as well as introducing other deficiencies.

70. Visualizing the temperature gradients—in this case,

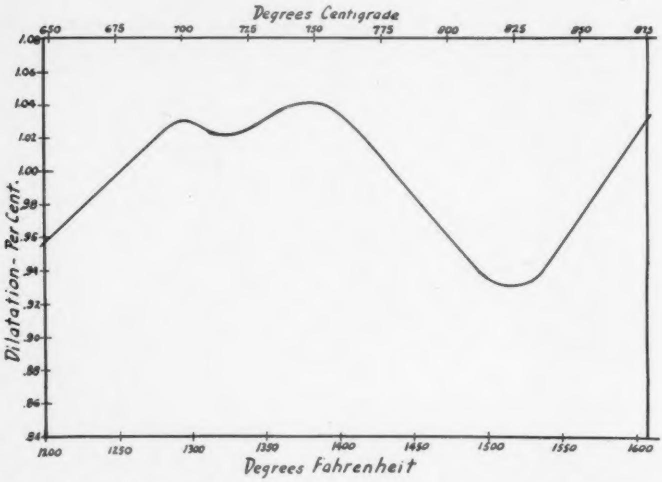

FIG. 11—DILATATION CURVE OF THE STEEL USED FOR MAKING THE CASTINGS SHOWN IN FIG. 10.

horizontally from hub to rim—it is apparent that at the moment the mold is filled the hub consists of the hottest metal contained in the hottest part of the mold. As the distance from hub increases, the temperature of both metal and mold decreases. While this is satisfactory from the viewpoint of securing adequate feeding from a riser imposed on the top of the hub it has certain adverse implications when the design is studied in relation to dilatation phenomena. A dilatation curve, typical of the steel in which these castings were produced, is shown in Fig. 11.

71. Remembering that pronounced temperature gradients,

correctly disposed for feeding, exist in both metal and mold, and that the metal temperature at the hub is probably at least 120 degrees Fahr. higher than at the rim, solidification—and subsequent cooling—proceeds selectively from rim to hub. The rim, being in contact with cool mold, cools down relatively rapidly and, down to 1544 degrees Fahr. (840 degrees Cent.) is constricting. In the early, and most rapid, part of this period the hub and the inner ends of the spokes are conceivably so hot as to respond readily to the stress without incurring any pronounced residual influence. At a later stage in the cooling of the casting the rim will be passing through the range 1544 degrees Fahr. to 1256 degrees Fahr. and will be expanding while the inner parts of the casting—hub and parts of the spokes—are constricting and contracting. It was in this thermal period that the few cases of hot tears at *A* (Fig. 10) were believed to be generated.

72. The significant points to be considered, in relation to design, are marked *X, X* in Fig. 10-A. All the way down to shop temperature the rim precedes the remainder of the casting in cooling, and in aggregation of strength down to the lower end of the blue-brittleness range. The points *X, X*—and similar locations diametrically opposed on the other spoke—become practically fixed points in their relation to the rim at *C, C* while the distance between them should decrease with falling temperature.

73. Thus, in the later stages of the cooling of the casting, the spokes were placed pronouncedly in tension of such magnitude as to lead to cold cracking in far too many instances.

74. It became apparent that the prime necessity was to permit the points *X, X* to move closer together in as full accord as possible with the normal uninterrupted contraction of cast steel. The design was accordingly modified to produce what is shown in Fig. 10-B. The head of the Y, Fig. 10-B, is produced as two curved members, each of which is of lighter section than the single member of the Y.

75. Given the same temperature gradients as the casting of the straight Y type, the points *Z, Z* could get closer together, the curved spoke-members deforming under the tension of the contracting "inner" parts of the casting. To avoid any misconception, it should be stated that the curved spoke-members were of the same cross-section as those of the relative parts of the straight Y spokes. The ability of the curved upper members to straighten—that is, to assume a larger radius—entirely elimi-

nated the cold-cracking trouble as well as the more rare occurrence of hot-tearing at the junction of a spoke with the hub.

76. This is the only example of design modification that the author proposes to submit in relation to the prevention of cold cracking. Others could be cited, and it is believed that most practical foundrymen could, from the wealth of their experience, quote instances of difficulties encountered. It is hardly possible to entertain the hope that all such difficulties could be overcome in a manner so simple as that which effected the cure in the case of the truck wheel.

77. No attempt will be made by the author to summarize as it is his opinion that the matter is too complex—despite the simple examples chosen for discussion—to admit of comprehensive accuracy. It is to be remembered that each casting presents its own peculiar problem and, while castings may be classified in types, seemingly small variations affect materially the classification.

78. For inability to clothe the concepts in words that will be explicit to all, the author tenders his apologies and undertakes to deal—within his limitations—as fully as possible with the matters that are bound to arise in the discussion.

DISCUSSION

In absence of the author, Mr. Batty's paper was presented by John Howe Hall, Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

C. W. BRIGGS[1] AND R. A. GEZELIUS[2] (*Written Discussion*): We wish to congratulate Mr. Batty on his excellent exchange paper to the British Foundrymen. We have long been keen followers of Mr. Batty's advocated directional solidification methods, so we may have been very much interested in this paper where the reversal method is so admirably set forth. We have only a few minor suggestions to offer and, as they are more in the nature of opinions than facts, they may not enhance or detract from Mr. Batty's ideas.

Since the actual temperatures of the steel are not known, it might be best when representing temperature gradients on a chart to designate the direction of temperature increase with an arrow instead of actually putting down the temperatures in intervals of 50 degrees Fahr. We believe that these gradients should actually be measured some time, though we realize how difficult it is to obtain such measurements.

We note that page 97 in paragraph 62, the figure of 0.00039 given

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[1, 2] Physical Metallurgist and Assistant Physicist, respectively, U. S. Naval Research Laboratory, Washington, D. C.

by McCance appears. We believe that this figure is of little value since in the first place no quantity is given, nor in McCance's article is there any reference made to such a quantity or how the figure was obtained. Data from other sources have been measured in specific volumes at a definite temperature and therefore have little bearing on McCance's figure.

On page 101, paragraph 71, Mr. Batty refers to the expanding of the rim and the contracting of the hub and calls attention to the range of 1544 to 1256 degrees Fahr. and states: "It was in this thermal period that the few cases of hot tears at A (Fig. 10) were believed to be generated." At first glance it seems that the author is referring to the fact that the hot tears occurred within the range 1544 to 1256 degrees Fahr. but on second thought it is observed that Mr. Batty refers to this range and also the temperature of the hub which we take is higher. Are we to assume that the hub temperature is considerably higher, say 2400 degrees Fahr.? This temperature gradient seems rather high to us. We take 2400 because our present work is leading us to believe that hot tears are formed somewhere between that temperature and the solidifying temperature. It has been pointed out previously that it is not necessary for expansion and contraction to be taking place simultaneously within a casting for the formation of hot tears; in fact, we believe two different amounts of contraction at high temperatures are all that is necessary. However, this is all a matter of opinion and at the present we have no figures to present.

GEORGE BATTY (*In Reply to the Written Discussion Submitted by Messrs. Briggs and Gezelius*): The temperature gradients which I have ventured to indicate by diagrams are based on visual observation amplified occasionally by the use of an optical pyrometer. However, that a pronounced modification occurs cannot be doubted because a pouring temperature of as low as 2830 degrees Fahr. was sufficient to run the castings completely provided pouring was rapid. With such a low initial temperature, however, it is fairly certain that the metal which formed the rim was almost at solidfication temperature when it came to rest. This would infer a temperature difference between hub metal and rim metal of probably 120 degrees Fahr. at the moment the mold was filled.

It is conceivable therefore that within quite a few seconds after mold was filled the temperature difference between hub and rim had increased to several hundred degrees. I would not like to hazard an opinion as to what difference of temperature between hub metal and rim actually occurs in the cooling period as a maximum, but I would say that the temperature gradient in such a casting must be rather a peculiar thing if accurately plotted as successive curves against time. On one or two occasions breakouts occurred after the mold was filled and I have seen the merest shell left at the hub, the spokes containing a very much elongated tapering cavity with very thin walls at the fillets and the rim as sound as was found to be normal on castings that had not broken out or been bled.

It is of course possible that on a casting of this design hot tearing may occur at temperatures below 1300 degrees Cent. (2372 degrees Fahr.) by reason of the abnormality of the stresses imposed, but despite this assumption in the specific case I am still in accord, in general, with your

belief that on most steel castings hot tearing occurs at temperatures in the region of, or above, 1300 degrees Cent. (2372 degrees Fahr.)

J. M. SAMPSON[3]: In so-called directional solidification, you will find, if you try to apply it in the usual general run of castings, especially in the large sizes, difficulties in tipping the mold up and back, particularly if they are core jobs. In fact, I think that Mr. Batty in a former paper mentioned the limitations regarding sizes. I would like to know if anyone here has had any experience in using metallic substances, such as very fine punchings from sheet steel, in their sand to extract the heat from those portions of the sand which it is desired to have cool at a faster rate than normal. Using punchings similar to stainless steels of the magnetic variety, these could be eliminated from the backing sand by passing it through a magnetic separator. These particles, being flat, would act somewhat as laminations throughout the sand and extract the heat.

Another thing we have found, particularly in some of the larger castings. We get improved practice, both as to freedom from tears and in elimination of erosion at the gate, from gating with a horn gate into a bottom riser. This is because many of our castings have fairly heavy flanges and heavy sections at the bottom which we have to feed with a blind riser. By getting this way, in preference to our previous methods, we have eliminated many tears and a great deal of dirt.

We have done some work along the line of metallic substances but I am not quite free yet to bring it out in the open because we are not quite sure of the results ourselves.

P. E. MCKINNEY[4]: I am sure that the series of papers which we have had for several years on these very important phases of steel founding, covering the more theoretical side with the one series of papers and the practical application to foundry methods in the other series, is one that should receive the fullest comment and discussion from everybody, and I can join the previous speakers in wishing that this would just be one of a continuing series of papers that we will have each year.

JOHN HOWE HALL[5]: Mr. Batty mentioned somewhere in this paper the use in ingot practice of copper stools instead of iron stools in promoting controlled directional solidification in ingots. I believe the most recent thing in ingot practice is the substitution of copper for iron in the stool on which the ingot mold sits, and that has accomplished a good deal in enabling the man who makes ingots to pour a sounder ingot.

Then Mr. Batty gets to the question of chills near the end of his paper. Putting these two things together I wonder whether we are not all asleep. We have waited a year to wonder whether or not a copper chill would be a great deal better in a steel casting than a steel chill. I know, personally, I am going to try it right away when I get back, if my foundry superintendent will go along.

GEORGE BATTY (*Written Reply to Discussion*): Mr. Sampson raises a point for discussion which appears, at different times, to have presented itself to various workers in the steel castings industry. Something is

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[4] Bethlehem Steel Co., Bethlehem, Pa.
[5] Taylor Wharton Iron and Steel Co., High Bridge, N. J.

sought which is intermediate between the available extremes of a heavy external chill and an ordinary sand mold.

The writer has a remote recollection of reading, about ten years ago, a British patent specification which sought to prescribe the use of steel shot, suitably bonded, as a molding material for specific application in locations where it was desirable to extract heat selectively from cast metal. I have no knowledge of such procedure being applied in production of steel castings except for a few experimental pieces which were not satisfactory, probably by reason of inadequate technique.

The use of sand-faced chills, devised to promote the controlled directional solidification of cast rolls is, I am informed, patented procedure. a cooling coil embedded in a sand mold has also been used to secure similar results and there seems no reason why the expedient suggested by Mr. Sampson should not have some value in practice. In order to be efficient, however, it would appear essential that the punchings should be located close to the mold-metal interface and that they should form substantial metallic continuities. Sand is a poor conductor of heat and the interposition of films of sand between successive layers of punchings would be likely to nullify the effect of all but the layer nearest to the mold face.

Without wishing to appear dogmatic, I would offer the opinion that "face nailing" offers better potentialities for controlling local chilling, the length of the nails and the quantity or total weight prescribing the chill effect. It must be conceded, however, that in many instances such "face nailing" is impracticable in some locations because of the design of the pattern, and in such conditions Mr. Sampson's suggested method may usefully be applicable as an alternative to the full external chill. Further, "face nailing" does not enhance the surface beauty of a casting and it certainly tends to increase cleaning costs. It would be well, therefore, to investigate carefully the potentialities of the expedient mentioned by Mr. Sampson.

The value of the principle of gating into the root of blind risers cannot be too strongly emphasized. Such method ensures that the "hot spots" are located outside the casting. It is assumed that the casting to which Mr. Sampson refers is a turbine cylinder, or is of a similar type having, in the pouring position, a heavy basal flange and a relatively light body section. Some founders prefer to cast such pieces with the flange uppermost in order to facilitate feeding, but with such a method is associated the necessity for hanging cores from the cope which generally involves such strengthening of the cores as to introduce serious resistance to the normal solid contraction of the casting.

By gating into the blind risers, when the piece is cast "flange down," it is possible to create temperature gradients in mold and metal that are adequate to insure general soundness of cast structure by reason of the relation of section thickness of feed heads, flange, and general body. Isolated heavy masses—ports, and end flanges—on or near the upper surface of the casting are served by orthodox open risers, usually top-fed direct from the ladle.

Mr. Hall mentions ingot stools of copper. I did not allude to these in my paper, but have drawn attention both to copper stools and copper molds for the production of steel ingots in unreported discussions at

former conventions. As I remember it, these allusions were made to illuminate my contentions in reference to "rate of feed demand"; in other words, to the rate at which heat is transferred from the cast metal to its coolant to promote the volume change in the liquid and solidification phases whereby a relatively small amount of metal superimposed as a feed head—preferably insulated—may be competent to feed adequately a casting which, in orthodox practice, would require a relatively large amount of metal imposed as risers.

Copper chills have been used and are efficient but dangerous. Only in a few instances have I found it impossible to achieve with cast steel or cast iron chills all that could be obtained with copper chills. The melting point of copper is too low for it to be safely used as an extended chill for steel castings if any appreciable amount of metal flows in contact with such chill. Tar, used as a surface dressing for such chills, tends to reduce the liability of fusion of the chill.

The foregoing comments must not be read to mean that I believe there is no place whatever for external chills of copper in the production of steel castings. It is quite probable that a larger experience may—as enlarging experience in the past has done—cause me to modify my expressed opinions.

The Expansion and Contraction of Molding Sand at Elevated Temperatures

H. W. Dietert* and F. Valtier†, Detroit, Mich.

Abstract

The authors have investigated the contraction and expansion of molding sands and have found that fineness, clay content, moisture, sea coal and mold hardness exert important effects on those two properties. They further explain that molding sands with improper expansion and contraction properties often are responsible for such defects as rat-tails and scabs. The authors describe the apparatus used for testing the expansion and contraction of molding sands and also tell how these properties may be controlled.

1. Molding sand is subjected to very sudden temperature changes when molten metal is poured into a mold. In addition to the suddenness of the temperature change, the magnitude is very large. Within a time interval as short as 10 seconds, a temperature change from 1800 to 2900 degrees Fahr. may be forced on the sand forming the face of a mold.

2. Very few materials are available that are capable of enduring these sudden large temperature changes. Molding sand has a real task to perform and it is evident from the casting defects that molding sand is taxed to its capacity. The condition of the sand must be most favorable to enable it to retain a perfect mold face up to the time that the molten metal solidifies and forms a casting.

3. The large temperature rise of the sand causes it to change appreciably in volume. This change requires rearrangement of the sand grains which may cause the face of the mold to crack, buckle or break off in small sections. The slightest mark or defect on the face of the mold will leave its costly defect mark on the surface of the casting.

4. It is therefore important to know the behavior of molding sand under elevated temperatures, for it is under this condition

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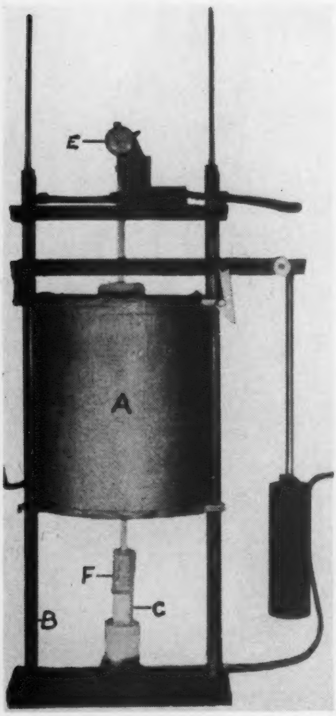
Note: This paper was presented at a session on Molding Sand Research held at the 1935 Convention of A.F.A. in Toronto, Canada.

that the casting is formed. A knowledge of the manner in which the expansion and contraction of molding sand may be altered will enable one to understand the causes of many casting defects, and to institute necessary changes to control the expansion and contraction of molding sand.



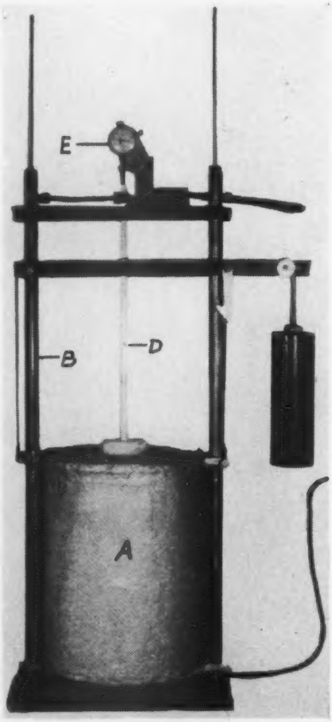


FIG. 1—DILATOMETER WITH FURNACE IN UPPER POSITION SHOWING SAND SPECIMEN.
FIG. 2—DILATOMETER WITH FURNACE IN THE LOWERED POSITION.

5. The expansion and contraction of molding materials may be determined by the dilatometer, as illustrated in Fig. 1. The dilatometer consists essentially of an electric furnace (A) supporting frame (B), alundum sand specimen support (C), silica rod (D), and a dial indicator (E).

6. The heating element of the electric furnace (A), consists of a platinum rhodium wire and is capable of operating safely up

to a temperature of 2500 degrees Fahr., which was found to be the maximum required for molding materials available.

7. The supporting frame (*B*) is built of brass tubing. Water is circulated through the tubing to maintain the frame at a constant temperature of 70 degrees Fahr. during the test period.

8. The sand specimen (*F*), Fig. 1, to be tested is $1\frac{1}{8}$ in. in diameter and 2 in. long. A silica plate is placed on each end of the sand specimen and the specimen is then placed on top of the alundum specimen support (*C*). The silica rod (*D*) is set on top of the sand specimen (*F*). The dial indicator (*E*) reading to 0.001 in. will show the change in the length of the sand specimen (*F*) as the temperature changes.

9. The sand specimen is inserted in the dilatometer when the furnace is in its upper position as shown in Fig. 1. The furnace is lowered, as shown in Fig. 2, to surround the sand specimen and subject it to elevated temperature.

10. Two methods of tests are available.

A. The furnace may be lowered while at room temperature, subjecting the sand to a gradual temperature rise of 10 degrees per minute up to 2500 degrees Fahr. and then allowing it to cool to room temperature. The dial indicator is read to determine the change in the sand specimen at 5 minute intervals.

B. The furnace may be heated to 1800 degrees Fahr. in upper position and then lowered, subjecting the sand to a sudden temperature rise. The temperature is then increased to 2500 degrees Fahr., after which the furnace is allowed to cool to 1800 degrees Fahr. The dial indicator is read at 5 minute intervals to obtain the maximum expansion and contraction of the sand specimen length.

11. The temperature of the furnace is obtained with a platinum-rhodium thermo-couple and a potentiometer, not shown in Figs. 1 or 2.

12. The sand specimen is rammed with a sand rammer, Fig. 3, employing a post type pedestal to secure the double end ramming. This method of ramming is used to secure a uniform ram for the small sand specimen used. The weight of the rammer block is 7 lbs. and a drop of $2\frac{1}{2}$ in. is used. Three drops of the rammer block are used to ram the sand specimen. This gives a mold hardness equivalent to the standard 2 in. A.F.A. sand specimen.

EXPANSION AND CONTRACTION OF MOLDING SAND UPON HEATING AND COOLING.

13. The facing sand of a mold is suddenly heated to a high

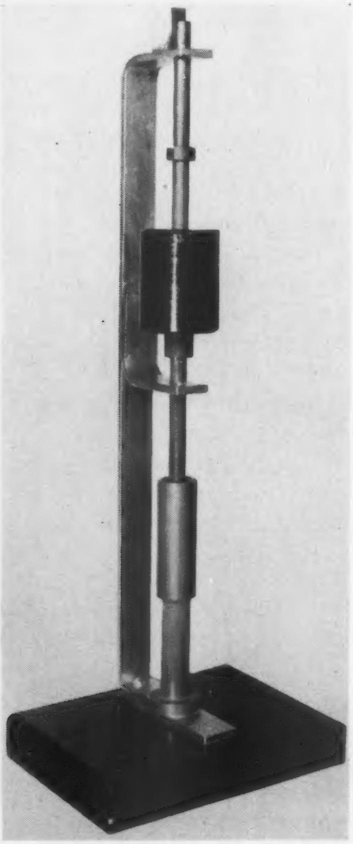


FIG. 3—SAND RAMMER FOR 1⅛-IN. DIAMETER SAND SPECIMEN, DOUBLE END RAMMED.

temperature while the backing sand is heated more slowly. It is therefore of interest to know the expansion and contraction of sand at various temperatures. One is also interested in knowing at what temperature the sand will stop expanding and start to contract.

14. These facts may be determined by placing a rammed

green sand specimen in the dilatometer, Figs. 1 and 2, with the furnace at room temperature. The reading of the dial indicator is noted and temperature raised to substantially 2500 degrees Fahr. at the rate of 10 degrees per minute. After a temperature of 2500 degrees is reached, the sand is allowed to cool. The change per inch in the sand specimen length is recorded during heating and cooling.

15. A graphical illustration of the expansion and contraction

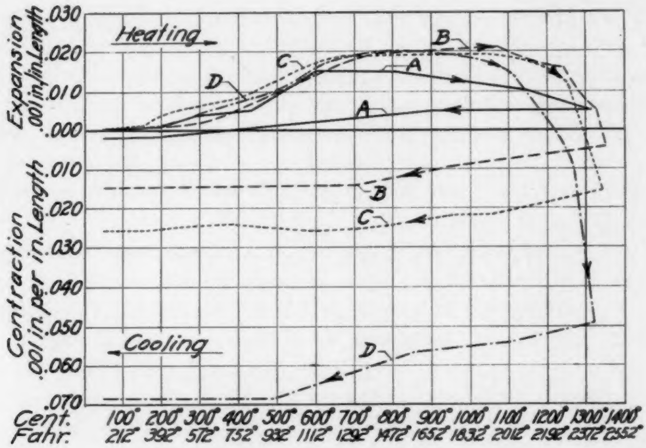


FIG. 4—DILATION CURVES SHOWING THE EXPANSION AND CONTRACTION OF FOUR MOLDING SANDS.

of four molding sands is shown in Fig. 4. Curves, as illustrated, are called dilation curves.

16. The heavy horizontal line corresponds to zero expansion and zero contraction. In other words, it is the original length of sand specimen at room temperature. The position of the dilation curve above this heavy line shows the amount of expansion over original length. The position of the curve below the heavy line shows the amount that the sand has contracted beyond original room temperature length.

17. A study of the dilation curve for the coarse grain sand *A* shows that this sand starts to expand appreciably at a temperature as low as 212 degrees Fahr. After a temperature of 850 degrees Fahr. is reached, the expansion increases rapidly. A maximum expansion of 0.016 in. per in. of specimen length is

reached at a temperature of 1200 degrees Fahr. As the temperature is increased to 1475 degrees Fahr., the sand begins to contract below the maximum expanded length. This contraction increases to 0.0118 in. per in. below the maximum length, or within 0.005 in. of original length, as the temperature is increased to 2400 degrees Fahr. As the sand specimen is then allowed to cool, the sand starts to contract slowly and when it finally reaches room temperature again, it is 0.002 in. shorter than the original length.

18. The grains of a molding sand consist mainly of quartz in the alpha state. When a temperature of 1069 degrees Fahr. is reached, the alpha quartz is changed to beta quartz. After this temperature is reached, the various dilation curves show little or no expansion due to the fact that beta quartz has no expansion. If no bonding material was present in the sand, a second rapid expansion increase would be noted at a temperature in the range of 2375 degrees Fahr. where the beta quartz would invert to tridymite.

19. Clay bond is present in molding sand and when it is subjected to temperatures of 1475 degrees Fahr., and up, it will begin to decrease in volume as shown by the drop of the dilation curve, Fig. 4. The temperature at which contraction begins depends upon the type of clay bond present in the sand. As an illustration, note the curve *B* where a temperature of 2000 degrees Fahr. is reached before contraction or fusion occurs. The sudden contraction drop in dilation curve corresponds to the sintering point temperature of the sand.

20. A comparison of the dilation curve in Fig. 4 shows sand *A* to have a maximum expansion of 0.016 in. per in.; *B*, 0.021 in. per in.; *C*, 0.019 in. per in.; and sand *D*, 0.020 in. per inch of length.

21. The temperature at which contraction begins, varies widely for the four sands, Fig. 4, namely from 1475 to 2000 degrees Fahr. The beginning of contraction is a practical index of the refractoriness of the sand.

22. The total contraction of the four sands after the specimens were heated to approximately 2400 degrees Fahr., or after the specimens were allowed to cool to room temperature, agrees as to order. The contraction at 2400 degrees Fahr. and at room temperature is tabulated below in Table 1.

23. Many casting defects are produced at high temperatures, thus one is interested in the contraction at high temperatures. With this in view, contraction at 2400 degrees Fahr. is a good

Table 1

Contraction at 2400 Degrees Fahr. and at Room Temperature of Four Sands in Fig. 4.

Sand	Contraction at 2400 degrees Fahr.	Contraction when cooled to Room Temperature
A	+0.005	—0.002
B	—0.0045	—0.015
C	—0.016	—0.026
D	—0.050	—0.069

practical index. A sand with a low contraction is to be preferred over one with high contraction.

24. The contraction of molding sand may be either less or much greater than the expansion. Contraction varies more for different molding sands than does expansion.

Expansion and Contraction of Sand in a Mold

25. A concrete example of the movement required between the sand grains to take care of expansion or contraction will stress the importance of a more thorough knowledge of this subject matter.

26. Choose a flask 60 in. long in which a casting 40 in. long is molded. Calculate the expansion of the sand *D*, as in Fig. 4, at a mold temperature of 1650 degrees Fahr. The expansion per inch equals 0.020 in. Multiply 0.020 by 40 in., which gives 0.80 in. total expansion. This increase of 0.80 in. of ex-

Fig. 5—Casting Showing "Rat-Tail" Defect.

panded sand must find space or else the mold face will be broken. A break or fracture of the mold wall will cause a defect termed "rat-tail", as illustrated in Fig. 5. It occurs in light weight casting where temperature of sand does not reach the contraction point, but sufficient heat is present to expand the sand.

27. The contraction of the sand *D*, illustrated in Fig. 4, when it is used as a facing sand where a temperature of 2400 degrees Fahr. may be reached, is 0.050 in. per in. of length. Multiply 0.050 in. by length of casting, for example 50 in., and the result is 2.5 in. contraction on face of mold. This amount of contraction

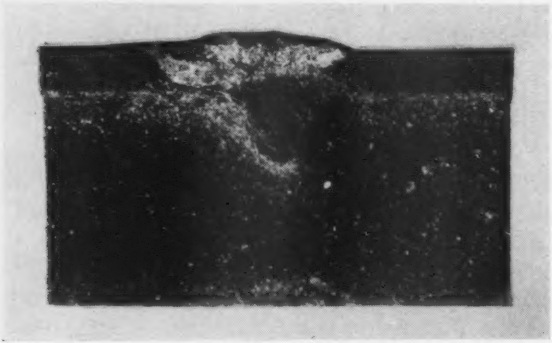


FIG. 6—CASTING SHOWING "SCAB" DEFECT.

certainly would cause open cracks in face of mold, into which molten metal would penetrate. In addition to this failure caused by contraction, one must consider that the backing sand behind the facing sand which is at a lower temperature will be expanded and will tend to push the facing sand into the molten metal.

28. This combination of excessive expansion and contraction, as obtained when sufficient weight of molten metal is present to raise the temperature of the sand to contraction point, is undoubtedly the best explanation of the direct cause of a "scab". A "scab" defect is shown in Fig. 6.

METHOD OF CONTROLLING EXPANSION AND CONTRACTION

29. Practically every material available expands or contracts as temperature changes. Our problem is to find means to control this behavior of material.

30. When the manner in which the different properties of a sand change the expansion and contraction is determined, a means of controlling this troublesome charactertistic of molding sand is available. Graphs will be presented showing how changes in the fineness, clay content, moisture, sea coal and mold hardness affect the expansion and contraction.

FINENESS CHANGES EXPANSION AND CONTRACTION

31. The fineness of a molding sand will affect the expansion and contraction due to the fact that the quality of the quartz varies as grain size changes. Also the rate at which heat will travel through a mass of sand in a mold will depend upon the permeability of the sand which is largely a function of the grain size. Heat travels through a mold, not by conduction from one sand

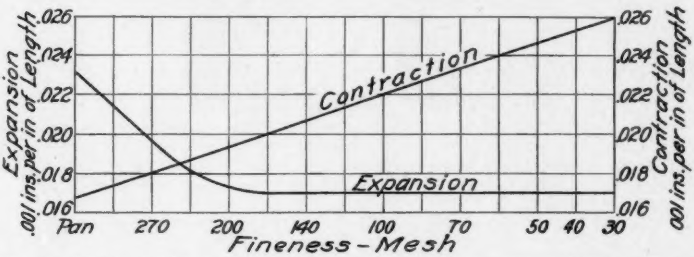


FIG. 7—EFFECT OF GRAIN SIZE ON EXPANSION AND CONTRACTION OF MOLDING SAND.

grain to the other, but by convection of hot gases. A sand of 100 permeability will heat up about twice as deep into the backing sand as a sand with a permeability of 50. It is desirable for large molds to have the heat travel through the sand quickly in order that the facing and backing sand will heat up more uniformly, thus expanding or contracting as one.

32. The expansion and contraction of molding sands, composed of various sized sand grains, is shown in Fig. 7. Sand grains of each grain size shown were bonded to 5.0 lbs. green compression strength with an Illinois clay. The synthetic sand for each mesh of grain size was placed in the dilatometer with furnace at 1800 degrees Fahr. and the test method *B* was followed, (see page 109).

33. The maximum expansion and total contraction as obtained are graphically shown in Fig. 7. It may be noted that the pan material has the greatest expansion of 0.0232 in. per in. The expansion drops quickly to 0.017 in. per in. as grain size increases

to 140 mesh. The expansion remains at 0.017 in. per in. as the sand grains become coarse. The contraction increases as the sand grains become coarse.

34. The greater contraction of the coarse sand does no apparent harm to the mold surface. On the left hand side in Fig. 8 is shown a 200 mesh sand specimen after heating to 2500 degrees Fahr. and on the right hand side a 70 mesh sand specimen is shown. The 200 mesh sand specimen is cracked, while the surface

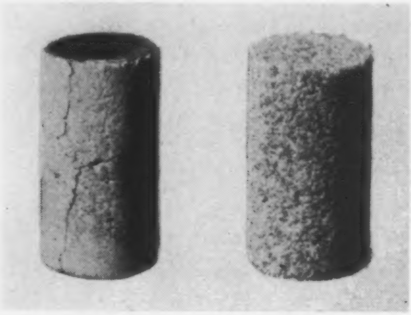


FIG. 8—SAND SPECIMEN AFTER HEATING TO 2500 DEGREES FAHR. LEFT—200 MESH SAND GRAINS. RIGHT—70 MESH SAND GRAINS.

of the 70 mesh specimen is intact. The finer the sand grains beyond 140 mesh, the larger the number of cracks appearing on the surface.

CLAY CONTENT CHANGES THE EXPANSION AND CONTRACTION

35. The quantity of clay bond present in a molding sand will affect the expansion of the sand materially.

36. Silica sand grains expand upon heating, while the clay bond contracts upon heating. One counteracts the other, namely, as clay increases, the expansion of the sand is reduced. This is graphically shown in Fig. 9, where the expansion and contraction for molding sand containing from 5 to 30 percent of clay is shown.

37. Ottawa silica sand was bonded with various percentages of Ohio clay. The synthetic molding sands thus secured were tested by method *B*, page 109, for expansion and contraction.

38. The sand with 5 per cent clay has an expansion of 0.027 in. per in. and a total contraction of 0.038 in. per in. A sand with 20 per cent clay has an expansion of 0.016 in per in. and a total contraction of 0.038 in. per in. The expansion of the sand

is undoubtedly reduced as clay content is increased by the shrinkage of the clay upon heating.

39. Clay addition is not a satisfactory medium to reduce the expansion of molding sand since clay reduces the permeability of the sand. The reduction in permeability will cause a non-uniform heating of molding sand, away from the mold wall, causing severe stresses to be set-up in the sand.

MOISTURE CHANGES THE EXPANSION AND CONTRACTION OF MOLDING SAND.

40. Moisture in molding sand influences the physical working properties of the sand more than any other element. Due to its great influence one would expect that moisture would change the

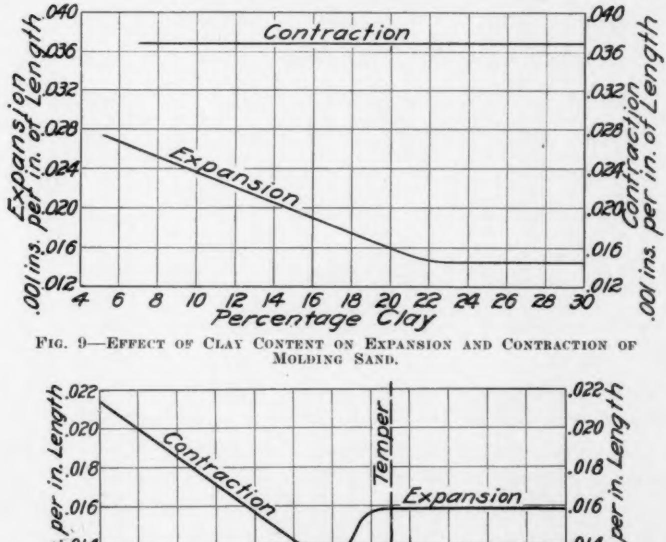


FIG. 9—EFFECT OF CLAY CONTENT ON EXPANSION AND CONTRACTION OF MOLDING SAND.

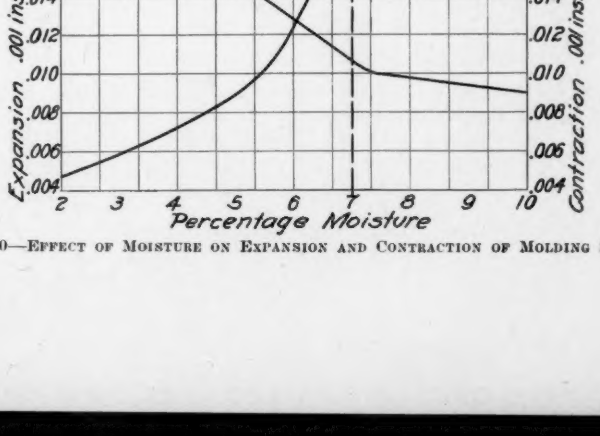


FIG. 10—EFFECT OF MOISTURE ON EXPANSION AND CONTRACTION OF MOLDING SAND.

expansion and contraction. Figure 10 shows the change in expansion and contraction as the moisture content of a natural plate molding sand is changed.

41. The sand is dry at 3.5 per cent moisture, at which point the expansion is 0.0063 in. per in. The sand is at correct temper when the moisture is 7 per cent and at this point the expansion has increased to 0.0159 in. per in. This is two and one-half times

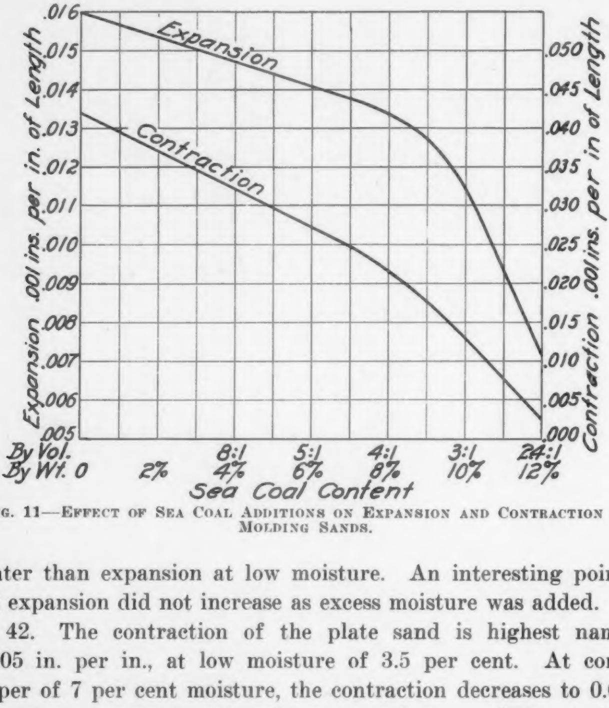


FIG. 11—EFFECT OF SEA COAL ADDITIONS ON EXPANSION AND CONTRACTION OF MOLDING SANDS.

greater than expansion at low moisture. An interesting point is that expansion did not increase as excess moisture was added.

42. The contraction of the plate sand is highest namely, 0.0205 in. per in., at low moisture of 3.5 per cent. At correct temper of 7 per cent moisture, the contraction decreases to 0.0105 in. per in., or approximately a 50 per cent decrease. When moisture is increased beyond the correct temper, the contraction decreases slowly.

SEA COAL CHANGES EXPANSION AND CONTRACTION OF MOLDING SAND

43. Sea coal is added to molding sand for the purpose of causing the sand to peel from the casting. The effect that it has on the sand receives little attention, for instance, the expansion and contraction.

44. Sea coal reduces both the expansion and contraction of molding sand, as is illustrated graphically in Fig. 11. The sand without sea coal has an expansion of 0.016 in. per in. and with 12 per cent sea coal the expansion is reduced to 0.007 in. per in. The contraction of the sand without sea coal is 0.0134 in. per in. and 0.0055 in. per in. when 12 per cent sea coal is present.

45. The marked reduction of the expansion and contraction of a sand as sea coal is added undoubtedly explains why the addition of sea coal is so beneficial in producing better castings. Sea coal and other combustible materials furnish a means of reducing both the expansion and contraction of molding sand.

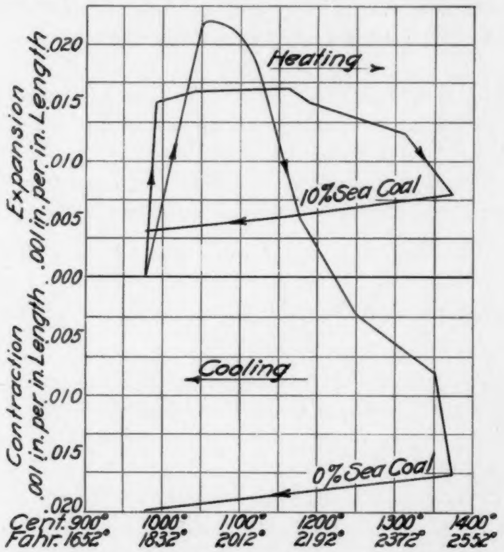


FIG. 12—EXPANSION AND CONTRACTION OF A MOLDING SAND WITH AND WITHOUT SEA COAL ADDITIONS.

46. The effect that sea coal has on the thermal volume change of molding sand is most clearly illustrated by the dilation curves of the sand with 10 per cent sea coal and sand without sea coal, as shown in Fig. 12. The furnace of the dilatometer was heated to a temperature near 1800 degrees Fahr. and then lowered around sand specimen, causing sand to be heated suddenly. Test method *B* was followed to secure dilation curves as shown in Fig. 12.

47. The dilation curve of the sand without sea coal covers a wide area, showing a maximum expansion of 0.021 in. per in.

After maximum expansion the sand begins to contract quickly. After the sand was allowed to cool to the starting temperature, the sand contracted to 0.020 in. per in. shorter than its original length.

48. The dilation curve of the same sand with 10 per cent sea coal added shows a curve which covers a very small area. A maximum expansion of 0.016 in. per in. was secured. The sand remains at a fairly constant volume from 1800 degrees to 2100 degrees Fahr. The sand without sea coal failed to remain at a constant volume over a 100 degree range.

49. The total contraction from maximum expansion volume of the sand with seal coal at 2000 degrees Fahr. is 0.008 in. per in., while the sand without sea coal has a total contraction of 0.036 in. per in.

50. The curves in Fig. 12 show that sand containing 10 per cent sea coal has a low expansion, a low contraction, a small thermal volume change and the thermal volume change is very gradual. Conversely, sand without sea coal has a high expansion, a high contraction, a large thermal volume change and the thermal changes take place suddenly.

MOLD HARDNESS CHANGES THE EXPANSION AND CONTRACTION OF MOLDING SAND.

51. Mold hardness furnishes an excellent means of altering properties of sand sufficiently to either make the sand suitable for a wide range of work or to cause it to be unsuitable even for the simplest of castings.

52. As mold hardness is increased the number of void spaces are reduced. A reduction of void spaces will compel more sand grains to stay in their rammed position, resulting in an increase of length of the sand mass when the sand grains expand.

53. When the sand is rammed at a low mold hardness, a large number of void spaces are present, allowing many sand grains to move into the voids, as the sand grains expand. It is therefore natural that the expansion of the sand will increase as is shown in Fig. 13. At a mold hardness of 20 the expansion of the sand is 0.0045 in. per in. and 0.019 in. per in. at a mold hardness of 96. Expansion is proportional to mold hardness. The above fact explains why molders remedy casting defects caused by mold wall failures by reducing the ramming.

54. The contraction of a sand decreases slightly as the mold hardness increases, due largely to a slight increase in refractoriness of the sand as it is rammed harder.

Casting Defects Caused by Expansion and Contraction

55. A very common casting defect that occurs on flat thin walled castings is a "rat-tail", as illustrated in Fig. 5. Excessive expansion of the molding sand causes defects of this type. It has been definitely proved that they may be eliminated when the expansion of the sand is reduced to 0.006 in. per in., by addition of a combustible material such as sea coal or by reducing the mold hardness of the mold.

56. Casting defects which commonly occur on heavy wall

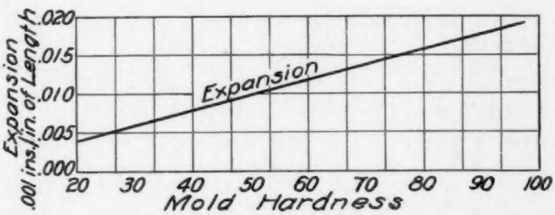


Fig. 13—Effect of Mold Hardness on the Expansion and Contraction of Molding Sand.

castings are "scabs", as illustrated in Fig. 6. Defects of this type are undoubtedly caused by a stress placed on the mold wall when sufficient heat is present to cause the facing sand to contract and the backing sand to expand. Fines should be reduced, thus increasing permeability, to obtain less expansion and to obtain a more uniform distribution of heat. A reduction of moisture, clay content or mold hardness also leads to corrective condition within the sand.

Conclusion

57. The importance of the change in the volume of the sand in a mold when the temperature is changed is sufficient to warrant detailed study by all foundrymen.

58. Good practice dictates that one know the behavior of material under thermal changes. Foundrymen may make definite advances in the molding art when they know the following relations.

1. Expansion of molding sand may be reduced by:
    a. Increasing grain size.
    b. Reducing the fines.
    c. Addition of combustible materials.
    d. Reducing the mold hardness.
    e. Increasing permeability.
    f. Reducing moisture.
2. Opposing stresses between expansion and contraction may be reduced by:
    a. Increasing grain size.
    b. Reducing the fines.
    c. Reducing mold hardness.
    d. Increasing permeability.
    e. Reducing moisture.
    f. Reducing clay content.

59. The expansion of molding sand is reduced upon continued use. Molding sand heated above 2400 degrees Fahr. will expand approximately one-half as much as the original sand. As an example, a natural molding sand as received, has an expansion of 0.0145 in. per in. and 0.008 in. per in. upon reheating to 2500 degrees Fahr.

60. Research work on the expansion and contraction of molding sands and cores should be continued to establish the many facts still uncovered. Casting contours which are inducive to defects caused by volume change of the sand should be determined. Further research work will enable foundrymen to obtain much relief from the ever present casting defects of the mold wall facture type.

DISCUSSION

CHAIRMAN H. B. HANLEY: Mr. Dietert, will you give us a word now, before the general discussion, on the expansion and contraction phenomena in core sands?

MR. DIETERT: We have worked a little on expansion and contraction of cores but our data accumulated so far are rather limited. They indicate that different silica sands have different expansions, as you might assume. The hardness of the core has an effect on the expansion. The type of bond and the moisture with which the sand is worked has an effect on the expansion and contraction.

I would say that there is just as much chance to control the expansion and contraction of cores as there is in the molding sand.

J. S. COXEY:[1] In the making of steel castings, with dry sand as compared to the green method, where your dry mold temperature is anywhere from 700 to 900 degrees Fahr., you are well over the change between the alpha and the beta. Has your shrinkage and contraction been greater in that instance than in the green sand casting?

MR. DIETERT: If I recall correctly, the alpha to beta point change occurs at about 1092 degrees Fahr. That is when the end point is reached.

If you dry the sand specimen before placing it in the dilatometer, you would get a slightly different beginning of the dilation curve but you will end up about the same. There is one difference and that is the interior of your dry sand acts a little different than it does for a green sand mold. In the dry sand, the interior would heat up a little faster, resulting in less surface cracks. Much research work is yet to be done on this subject matter.

MR. COXEY: When you have a fairly heavy mold wash with silica flour, which would be more refractory than the sand behind it, would there be any apparent difference in the surface of the mold?

MR. DIETERT: Yes, the backing sand is protected since the silica wash retards the flow of the hot gases and the hot gases heat up the backing sand of the mold. Mold wash, such as a silica flour wash, should receive a great deal of attention in a steel foundry. I believe many are probably using a mold wash that is too fine. A very fine ground silica flour has a higher expansion than a coarser ground silica flour.

MR. COXEY: If you would use a sand, say, for dry sand work, all passing through the 20 mesh sieve, with 75 per cent of it remaining on the 40, and the remainder on the 60, how would you bond that for dry sand work sufficiently enough to get away from the contraction and expansion?

MR. DIETERT: You will never get away from contraction and expansion entirely. You are now probably putting in some organic material which is combustible and which reduces expansion and contraction. A fairly open sand, such as you describe, does not contain much fines and has a low expansion. It is practically free of grains finer than 140, so you have eliminated the high expansion material. The only place you are putting high expansion material is on the face of your mold in the form of a wash.

I believe that if you would start some research on that, much information could be developed in determining the types of mold washes that expand within safe limits. Some physical treatment or some addition, or possibly a different fineness of silica flour would yield a much different mold condition. A change in the fineness of silica flour changes the expansion quickly.

CHAIRMAN HANLEY: I have known for a number of years about the application of ground wood flour to facing sand both in the steel foundry and in the cast iron foundry. Would the presence of such material be advantageous in reducing expansion and contraction to any extent?

[1] Industrial Silica Corp., Youngstown, Ohio.

MR. DIETERT: We have never tried wood flour mixtures in our dilatometer tests to see how they would react on the expansion and contraction, but from the information at hand, I would say it indicates that wood flour would reduce the expansion. Whether wood flour would really increase the sintering point or not, I doubt very much.

M. R. TAGGART:[2] What effect in regard to the cleaning of the castings does this contraction of molding sand have?

MR. DIETERT: That is a very practical question. You naturally would agree with me that the more casting surface defects, such as scabs, seams, buckles and other defects, the more will your cleaning room cost be increased. Now, as you decrease the contraction, you get a better finish, because as you decrease the contraction, you generally increase the refractoriness of the molding sand and, naturally, the more refractory the material is, the cleaner the casting will be due to less sand burn. Probably the best thing to do is to carry on research to determine the refractoriness of a sand by the casting method, or by the sintering test, or contraction test, or by a cone fusion test.

MR. TAGGART: Suppose you have a sand with a high sintering point, one where the contraction starts after the metal has cooled off to a point where it is below the sintering point, and then the sand contracts? Then what effect does it have on the cleaning of the casting?

MR. DIETERT: I don't think it has any, because just a few seconds after the casting is poured, and in that portion of the mold away from the gate, there is formed a paper-thickness skin of solidified metal which protects the sand. After that point, sand may crack underneath the skin of metal without leaving a defect mark on the casting surface.

MR. TAGGART: In other words, the sand would have a tendency to clean itself and separate itself from the casting and therefore the cleaning would be easier.

MR. DIETERT: That is correct.

[2] Taggart and Co., Philadelphia, Pa.

Impact Resistance and Other Physical Properties of Alloy Gray Cast Irons

By Garnet P. Phillips,* Chicago, Ill.

Abstract

To determine impact resistance of alloy cast irons, samples from 38 cupola heats and 20 electric furnace heats were tested. Alloy additions used were chromium, molybdenum, nickel, copper and titanium. In addition to impact test results, tests on other physical properties were made. Ten heats of the electric furnace irons were heat treated. The effects of the alloys on the physical properties are compared and discussed. Test results indicate that in the case of irons cast gray and omitting austenitic irons, fairly high carbon nickel-molybdenum irons that may contain some chromium, have good impact resisting properties. The highest impact resistance was obtained on irons cast white and converted to gray irons by annealing. Transverse resilience correlates fairly closely with impact resistance and single blow impact tests made on machined bars apparently correlates with transverse resilience more closely than does the repeated drop test on unmachined bars.

1. During 1934 and the early part of 1935, while the writer was metallurgist for the Frank Foundries Corporation, Moline, Ill., we had occasion to investigate the impact resistance of some alloy cast irons, in connection with some work on castings requiring shock resistance. All of the test bars on both cupola and electric furnace iron were made at the Frank Foundries Corporation plant and most of the chemical and physical tests were made in their laboratory, with the exception of impact tests that were made as later noted in the report.

2. After the work was in progress it was also decided to investigate some of the cupola and electric furnace irons produced daily and to make a somewhat limited investigation of the

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Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

effects of individual alloys and alloy combinations on impact resistance and other physical properties.

CUPOLA IRONS

3. Cupola irons investigated were made with 10 per cent or 23 per cent steel-mix charges, with the exception of No. 1 iron given in Table 1 which was a soft gray iron made with a straight pig and scrap mix. This latter iron was non-alloyed and was included for comparative purposes.

TRANSVERSE AND HARDNESS TESTS

4. The data given were all obtained on standard A.S.T.M. bars of 1.20-in. diameter which were broken on 18.0-in. supports in the transverse tests. Transverse test results given in the tables are the averages of two and, in some cases, three tests. Modulus of rupture is given for the average transverse breaking load. Relative modulus of elasticity was calculated at one quarter of the ultimate transverse strength.

5. All hardness tests were made on sections cut from the broken transverse bars at the break. Hardness tests were made midway between center and edge on all pieces. Brinell hardness tests given in the tables are the averages of two tests while the Rockwell tests given are the averages of four tests in each case.

TRANSVERSE RESILIENCE

6. Transverse resilience, given in inch-pounds, is the area under the transverse load-deflection curve and represents the energy expended in breaking the bars. The transverse resilience may be changed from inch-pounds to foot-pounds by dividing by twelve.

IMPACT TESTS

7. Repeated drop impact tests were made in duplicate and average results of the two tests are given in the tables. Unmachined halves of the 1.20-in. diameter transverse bars were used and tested on supports 6 inches apart. A 25 lb. hammer was used and allowed to drop one inch at the start of each test. Each succeeding drop was made from an increased height of one inch until failure occurred. The height of drop of the final blow is given in inches in the tables with no corrections for frictional losses. The repeated drop impact values may be changed from inches to foot-pounds by multiplying by 2.083.

8. Single blow impact tests were made on a Charpy type machine on halves of transverse bars ground to 1.125-in. diameter. The bars were tested on supports 6 inches apart and the capacity of the machine was 125 ft. lb. Somewhat less than a third of the irons investigated were subjected to the single blow impact test.

CHEMICAL AND PHYSICAL PROPERTIES

9. Chemical analyses and physical properties of the cupola melted irons are given in Tables 1 and 2, respectively. Transverse

Table 1

CHEMICAL ANALYSES OF CUPOLA IRONS

Iron No. %	Si., %	T.C., %	Gr., %	CC., %	S., %	P., %	Mn., %	Ni., %	Cr., %	Mo. and Ti. %
1	2.29	3.63	2.91	0.72	0.11	0.31	0.57	....	....	....
2	2.25	3.53	2.96	0.57	0.05	0.14	0.59	0.71	0.25	....
3	2.03	3.49	2.87	0.62	0.72	0.17	0.58	0.51	0.24	....
4	1.95	3.49	2.82	0.67	0.07	0.15	0.61	0.70	0.25	....
5	2.23	3.38	2.74	0.64	0.06	0.14	0.60	1.46	0.15	....
6	2.07	3.44	2.81	0.63	0.07	0.16	0.60	0.35	0.20	....
7	2.24	3.33	2.62	0.71	0.07	0.16	0.58	0.68	0.22	....
8	2.01	3.36	2.66	0.70	0.06	0.14	0.62	1.10	0.66	....
9	2.12	3.44	2.70	0.74	0.05	0.16	0.60	1.01	0.24	0.60 Mo.
10	2.11	3.41	2.69	0.72	0.04	0.16	0.60	1.95	0.21	0.90 Mo.
11	2.02	3.25	2.53	0.72	0.06	0.15	0.64	1.23	0.28	0.50 Mo.
12	2.22	3.20	2.50	0.70	0.06	0.15	0.61	2.16	0.22	0.85 Mo.
13	2.14	3.47	2.72	0.75	0.06	0.15	0.65	0.40	0.23	....
14	2.21	3.49	2.70	0.79	0.05	0.15	0.65	0.41	0.72	....
15	2.26	3.47	2.37	1.10	0.05	0.15	0.62	0.40	1.18	....
16	2.32	3.47	2.30	1.17	0.06	0.15	0.63	0.42	1.37	....
17	2.12	3.49	2.87	0.62	0.07	0.16	0.60	0.38	0.24	....
18	2.12	3.44	2.73	0.71	0.07	0.64	0.60	0.38	0.24	....
19	2.12	3.38	2.64	0.74	0.07	0.97	0.60	0.38	0.24	....
20	2.12	3.28	2.60	0.68	0.07	1.48	0.60	0.38	0.24	....
21	2.09	3.41	2.72	0.69	0.05	0.17	0.60	0.32	0.23	....
22	2.09	3.41	2.72	0.69	0.05	0.17	0.60	0.72	0.23	....
23	2.09	3.33	2.61	0.72	0.05	0.17	0.60	1.31	0.23	....
24	2.09	3.28	2.62	0.66	0.05	0.17	0.60	1.80	0.23	....
25	2.07	3.38	2.62	0.76	0.09	0.15	0.59	0.44	0.24	....
26	2.07	3.36	2.68	0.68	0.09	0.15	0.59	0.44	0.24	0.30 Mo.
27	2.07	3.36	2.68	0.68	0.09	0.15	0.59	0.44	0.24	0.50 Mo.
28	2.07	3.33	2.57	0.76	0.09	0.15	0.59	0.44	0.24	0.80 Mo.
29	2.09	3.38	2.65	0.73	0.06	0.16	0.62	0.45	0.23	....
30	2.09	3.36	2.60	0.76	0.06	0.16	0.62	1.25	0.53	....
31	2.09	3.33	2.44	0.89	0.06	0.16	0.62	1.77	0.74	....
32	2.09	3.33	2.46	0.87	0.06	0.16	0.62	2.07	0.92	....
33	2.00	3.33	2.64	0.69	0.10	0.19	0.60	0.31	0.13	....
34	2.00	3.38	2.72	0.66	0.10	0.19	0.60	0.31	0.13	....
35	2.13	3.44	2.68	0.76	0.07	0.15	0.64	1.23	0.67	....
36	2.19	3.44	2.69	0.75	0.06	0.15	0.64	1.23	0.67	0.06 Ti.
37	2.07	3.47	2.84	0.63	0.06	0.15	0.65	0.40	0.17	....
38*	2.14	3.47	2.64	0.83	0.06	0.15	0.64	0.40	0.54	0.07 Ti.

* 1.30% copper.

load deflection curves for the 38 cupola irons are shown in Fig. 1. Chemical analyses and physical properties of the electric furnace irons are given in Tables 3 and 4 while the transverse load-deflection curves for the same irons are shown in Fig. 2. The data on single blow impact tests are given in Table 5 and include 10 cupola irons and 7 electric furnace irons.

10. As stated previously, cupola iron No. 1 was a high carbon, soft gray iron made with a pig-scrap mix. This iron had the

Table 2

PHYSICAL PROPERTIES OF CUPOLA IRONS

	Transverse Test			Hardness Tests		Tensile Tests,	Moduli of		Impact
Iron No.	Load, lb.	Deflection, in.	Resilience, in lb.	Brinell	Rockwell-B	lb. per sq. in. sq. in.	Rupture, lb. per sq. in thousands	Elasticity, lbs. per sq. in. millions	Repeated Drop, in.
1	1940	0.315	363	164.5	83.0	21,290	51.5	11.8	8.0
2	2100	0.310	410	173.0	85.5	24,610	55.7	12.0	10.0
3	2485	0.335	489	184.0	87.7	31,420	65.8	14.2	12.5
4	2526	0.305	444	187.0	89.5	32,910	67.0	13.0	12.5
5	2615	0.352	533	187.0	88.5	29,900	69.3	12.8	11.5
6	2460	0.350	509	176.5	85.7	30,200	65.3	13.3	12.5
7	2725	0.335	520	199.0	90.0	34,830	72.3	15.3	15.0
8	2845	0.292	454	214.5	94.2	39,970	75.5	15.1	12.0
9	3040	0.355	626	212.0	93.5	38,400	80.7	13.9	18.5
10	3290	0.460	927	251.5	99.7	43,800	87.2	12.9	19.0
11	3185	0.343	563	225.5	95.2	42,830	84.5	14.4	18.5
12	3490	0.455	906	281.5	33.7	*C49,680	92.5	12.5	16.5
13	2460	0.290	410	192.0	89.2	33,080	65.3	14.9	10.5
14	2640	0.312	458	204.5	93.0	34,060	70.3	13.9	12.5
15	2500	0.245	324	228.0	95.5	33,465	66.3	14.9	11.5
16	2300	0.215	270	255.0	100.5	......	61.0	15.2	9.0
17	2405	0.320	456	184.0	89.0	29,940	63.8	12.9	12.5
18	2250	0.260	329	194.0	91.5	28,150	59.8	13.4	11.5
19	2050	0.215	235	194.0	91.5	26,310	54.4	13.5	9.5
20	1680	0.160	139	218.5	94.7	27,860	44.5	13.9	6.0
21	2360	0.260	341	194.0	90.0	33,140	62.6	13.8	11.5
22	2410	0.290	395	196.0	91.2	33,360	63.8	13.8	10.0
23	2360	0.285	371	192.0	90.2	31,870	62.6	13.8	12.0
24	2450	0.310	431	192.0	90.0	32,680	65.0	12.5	11.0
25	2350	0.298	416	189.5	89.2	31,470	62.3	14.5	15.5
26	2425	0.295	417	196.0	91.5	34,340	64.3	12.0	12.0
27	2785	0.310	493	209.5	93.0	38,730	74.0	14.0	12.0
28	2805	0.305	477	217.0	94.5	41,190	74.4	14.1	14.0
29	2485	0.308	446	187.0	89.5	33,470	66.0	12.6	12.0
30	2600	0.310	461	207.0	92.2	35,160	69.0	13.3	14.0
31	2625	0.290	420	213.5	93.5	36,210	69.5	13.9	12.5
32	2485	0.258	339	228.0	96.0	37,170	66.0	14.8	11.0
33	2627	0.335	463	185.0	88.5	33,340	69.7	13.9	13.0
34	2525	0.370	533	172.0	85.2	28,920	67.0	13.4	12.0
35	2565	0.277	398	209.5	94.5	35,060	68.0	14.4	10.5
36	2787	0.287	453	223.0	96.5	39,000	73.8	15.1	11.5
37	2412	0.305	425	189.5	90.5	33,090	64.0	13.8	11.0
38	2895	0.297	487	223.0	97.2	38,150	76.8	14.8	12.0

*C—Scale.

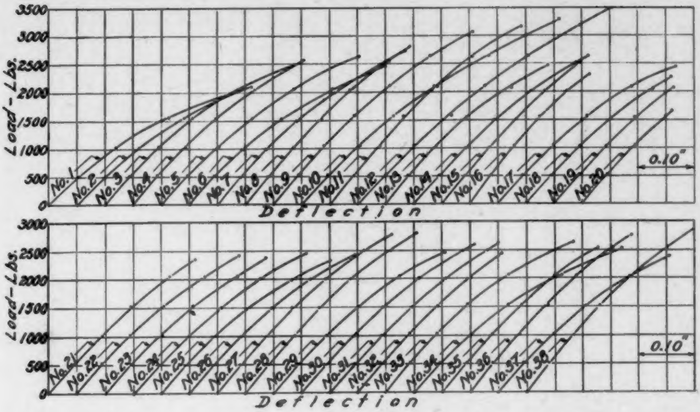


FIG. 1—TRANSVERSE LOAD-DEFLECTION CURVES FOR CUPOLA IRONS NOS. 1 TO 38 INCLUSIVE. BARS 1.20-IN. DIAMETER BROKEN ON 18-IN. SUPPORTS.

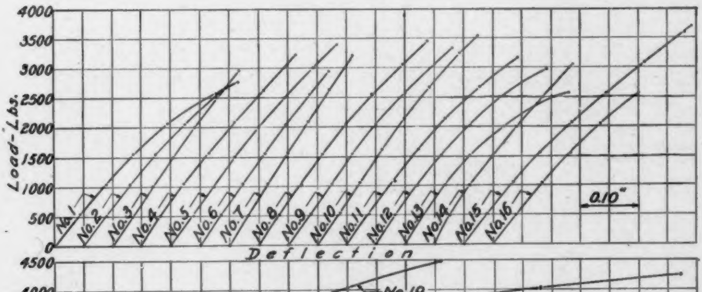


FIG. 2—TRANSVERSE LOAD-DEFLECTION CURVES FOR ELECTRIC FURNACE IRONS NOS. E1 TO E16 INCLUSIVE. BARS 1.20-IN. DIAMETER BROKEN ON 18-IN. SUPPORTS.

Table 3

CHEMICAL ANALYSES OF ELECTRIC FURNACE IRONS

Iron No.	Si., %	T. C., %	Gr. %	CC., %	S., %	P., %	Mn., %	Ni., %	Cr., %	Mo. %	Cu. %
E 1	2.73	2.98	2.34	0.64	0.073	0.122	0.62	0.37	0.20	....	....
E 2	2.16	3.00	2.27	0.73	0.070	0.118	0.60	0.84	0.20	....	....
E 3	2.47	2.54	1.82	0.72	0.038	0.114	0.55	1.41	0.36	0.40	....
E 4	2.64	2.70	1.96	0.74	0.054	0.209	0.46	1.68	0.38	0.40	....
E 5[1]	1.93	3.00	2.21	0.79	0.019	0.124	0.56	0.76	0.19	0.50	....
E 6[2]	1.95	2.78	2.08	0.70	0.043	0.124	0.49	1.68	0.19	0.63	....
E 7[3]	2.24	2.65	1.91	0.74	0.063	0.116	0.50	1.33	0.15	0.60	....
E 8	1.87	2.89	2.15	0.74	0.056	0.198	0.46	1.61	0.41	0.60	....
E 9	1.99	2.95	2.19	0.76	0.047	0.115	0.58	1.49	0.41	0.60	....
E 10[4]	2.13	2.95	2.12	0.83	0.107	0.153	0.57	1.04	0.08	0.70	....
E 11[5]	2.00	3.11	2.16	0.95	0.064	0.264	0.61	1.38	0.14	0.70	....
E 12[6]	1.95	2.87	2.45	0.42	0.044	0.219	0.59	1.71	0.14	0.95	....
E 13[7]	2.02	3.08	2.70	0.38	0.061	0.178	0.57	1.33	0.12	0.90	....
E 14[8]	2.35	2.49	1.91	0.58	0.062	0.112	0.87	1.56	0.28	1.00	....
E 15	2.57	2.81	2.08	0.73	0.047	0.155	0.51	1.91	0.18	0.90	....
E 16[9]	0.90	3.88	2.87	1.01	0.076	0.046	0.45	1.42	0.47	0.38	....
E 17	2.27	2.89	2.12	0.77	0.072	0.167	0.97	12.80	2.12	....	6.24
E 18	2.37	2.87	2.24	0.63	0.089	0.122	0.61	13.71	3.81	....	6.27
E 19[10]	1.33	2.16	1.48	0.68	0.046	0.098	0.43	0.11	0.07	0.50	....
E 20[11]	1.33	2.32	1.61	0.71	0.060	0.114	0.50	0.19	0.04	0.30	....

[1]Normalized at 1000° F. for 1 hour. Slowly cooled.
[2]Annealed at 1150 to 1175° F. for 1 hour. Slowly cooled.
[3]Normalized at 900 to 1000° F. for 1 hour. Slowly cooled.
[4]Normalized at 1000° F. for 1 hour. Slowly cooled.
[5]Normalized at 1000° F. for 1 hour. Slowly cooled.
[6]Annealed at 1150° F. for 1 hour and slowly cooled. Reannealed at 1275 to 1300° F. for 1 hour and slowly cooled.
[7]Annealed at 1275 to 1300° F. for 1 hour and slowly cooled.
[8]Annealed at 1300 to 1325° F. for 1 hour and slowly cooled.
[9]Normalized at 1000° F. for 1 hour. Slowly cooled.
[10]Cast white and annealed at 1775 to 1800° F. for 4½ hours. Cooled at average rate of 104° F. per hour to 1200 F.
[11]Cast white and annealed at 1775 to 1800° F. for 4½ hours. Cooled at average rate of 85° F. per hour to 1200° F.

lowest impact value of all with the one exception, the No. 20 iron, which had 1.48 per cent phosphorus. Cupola irons Nos. 4, 5, 6, 7, 8, 11, 12, 33, 34, 35 and 36 were made with 23 per cent steel mixture, while all other cupola irons tested were made with a 10 per cent steel mixture.

11. *Nickel-Molybdenum*—The effect of nickel-molybdenum additions on impact and other properties are shown by results obtained on iron No. 13, as a base metal, compared with those of irons Nos. 9 and 10. In the case of No. 9 metal, increasing nickel from 0.40 per cent to 1.01 per cent and adding 0.60 per cent molybdenum has resulted in a marked increase in hardness and all physical properties. The impact (repeated drop) was raised from 10.5 in. to 18.5 in. No. 10 iron shows the effect of further increase in nickel and molybdenum. The repeated drop impact is raised to 19.0 in. No. 9 iron tested 44.5 ft. lb. in the single blow test while No. 10 iron tested 76.0 ft. lb.

12. Cupola irons Nos. 11 and 12 show effects of nickel-molybdenum additions to the 23 per cent steel mix metal. Increasing nickel-molybdenum resulted in increase in all properties with the exception of the repeated drop impact. No. 12 iron with higher alloy content tested lower in the repeated drop test yet higher in the single blow impact test. In general, an increase in nickel-molybdenum content resulted in an increase in all physical properties. Both nickel and molybdenum were added to the ladle in these tests.

13. *Chromium*—Cupola irons Nos. 13, 14, 15, and 16, show the effect of chromium on physical properties. Chromium was added as fairly high silicon ferrochrome to the ladle. No. 13 iron was the base iron while No. 14, 15 and 16, were the same metal with increasing chromium content.

14. The hardness increased in proportion to the increased chromium content. The tensile strength and repeated drop impact increased in the No. 14 iron containing 0.72 per cent chromium but the impact decreased with further increase in chromium while

Table 4

PHYSICAL PROPERTIES OF ELECTRIC FURNACE IRONS

Iron No.	Transverse Test: Load, lb.	Transverse Test: Deflection, in.	Transverse Test: Resilience, in lb.	Hardness Tests: Brinell	Hardness Tests: Rockwell-B	Tensile Tests, lb. per sq. in.	Modulii of Rupture, lb. per sq. in thousands	Modulii of Elasticity, lb. per sq. in. millions	Impact Repeated Drop, in.
E 1	2767	0.315	498	196.0	91.2B	40,050	74.3	14.7	12.5
E 2	2670	0.242	345	225.5	94.7B	47,280	70.8	15.9	12.5
E 3	2950	0.217	334	269.0	30.0C	56,760	78.3	15.8	12.0
E 4	3225	0.265	472	269.0	30.2C	52,740	85.5	18.4	17.0
E 5	3400	0.285	506	244.5	99.0B	55,350	90.2	16.0	14.0
E 6	2985	0.220	335	273.0	31.0C	53,640	79.2	17.7	12.5
E 7	3220	0.210	322	316.0	34.7C	54,280	85.5	19.2	14.0
E 8	3490	0.290	549	265.5	98.2B	55,620	92.6	17.3	14.0
E 9	3325	0.280	506	262.0	97.7B	55,780	88.2	16.7	15.5
E 10	3520	0.275	511	255.0	100.0B	57,840	93.3	17.2	14.0
E 11	3170	0.295	508	228.0	96.0B	47,840	84.0	15.7	14.0
E 12	2972	0.290	505	170.0	84.5B	43,300	78.7	18.1	18.0
E 13	2532	0.280	447	170.0	84.0B	37,290	67.0	18.8	16.5
E 14	3050	0.234	360	251.0	98.5B	64,120	80.9	20.1	10.3
E 15	3715	0.390	792	297.5	34.0C	66,300	98.5	15.3	18.5
E 16	2575	0.250	355	209.5	93.3B	29,790	68.3	15.3	7.0
E 17	2563	0.500	882	151.0	81.2B	28,440	68.0	15.3	21.0
E 18	2240	0.385	559	172.0	84.0B	28,400	59.3	13.9	11.0
E 19[1]	4430	0.560	1804	231.5	97.2B	86,100	117.5	28.0	33.0
E 20[2]	4211	0.920	3082	159.0	85.0B	61,150	111.7	24.1	Note*

[1]Elongation in 2 inches 2.0 per cent.

[2]Elongation in 2 inches 3.0 per cent.

*Note.—Did not break at maximum capacity of machine of 40 inches.

tensile strength was about equal to that of the base metal. Transverse resilience followed the same trend as the repeated drop impact.

15. *Phosphorus*—Irons Nos. 17, 18, 19, and 20 show effect of phosphorus on physical properties. No. 17 iron was the base

Table 5

TRANSVERSE RESILIENCE, REPEATED DROP IMPACT AND SINGLE BLOW IMPACT FOR SOME CUPOLA AND ELECTRIC FURNACE IRONS

Iron No.	Transverse Resilience, in. lb.	Repeated Drop Impact, in.	Single Blow Impact, ft. lb.
	CUPOLA IRONS		
1	363	8.0	25.0
2	410	10.0	33.0
3	489	12.5	37.0
4	444	12.5	31.5
5	533	11.5	34.0
8	454	12.0	33.0
9	626	18.5	44.5
10	927	19.0	76.0
11	563	18.5	50.0
12	906	16.5	71.0
	ELECTRIC FURNACE IRONS		
E 6	335	12.5	23.0
E 7	322	14.0	26.0
E 15	792	18.5	48.0
E 16	355	7.0	21.5
E 17	882	21.0	117.0
E 18	559	11.0	50.2
E 20	3082	Note*	Note*

*Note.—In repeated drop test E20 iron did not break at capacity of machine of 40 inches. In single blow test, the bar could not be broken at the capacity of machine which was 125 ft. lb. The bar was ground to 0.75-in. diameter and broke at 36.5 ft. lb.

comparison metal. The increase in phosphorus resulted in an increase in hardness, a slight decrease in tensile strength and a marked decrease in transverse strength, transverse resilience and impact resistance. The total carbon was decreased considerably by the increase in phosphorus.

16. *Nickel*—Irons Nos. 21, 22, 23 and 24 show the effect of nickel on the physical properties of a medium total carbon iron. No. 21 was the base comparison metal. Increasing nickel resulted in a decrease in total carbon, little change in hardness, tensile

strength and impact resistance but resulted in an increase in transverse strength and resilience.

17. *Molybdenum*—Irons Nos. 25, 26, 27, and 28 show the effect of molybdenum on the physical properties. No. 25 iron was the base comparison metal. Increase in molybdenum resulted in an increase in hardness, tensile strength, transverse strength and resilience. The impact resistance of the base iron was unusually high for some unknown reason and the higher molybdenum irons showed lower impact values for this reason. We believe that normally the impact values will increase with increasing molybdenum content.

18. *Nickel-Chromium*—Irons Nos. 29, 30, 31, and 32 show the effect of nickel-chromium on the physical properties. Increasing nickel-chromium content resulted in an increase in hardness and tensile strength. Transverse strength, transverse resilience and impact values increased in iron No. 30 with 1.20 per cent nickel and 0.53 per cent chromium but decreased with higher nickel-chromium contents.

19. *Carbon*—Irons Nos. 33 and 34 show the effect of the addition of carbon in the form of graphite to the ladle. An addition of 0.50 per cent was made in the ladle but the recovery was low with only 0.05 per cent carbon increase. This small increase resulted in a marked decrease in hardness.

20. The transverse load was decreased but deflection increased. The transverse resilience was increased and impact resistance decreased slightly. The tensile strength was decreased. It might be well to note that chilling tendency of the metal was decreased markedly.

21. *Titanium*—Irons Nos. 35 and 36 show the effect of a small amount of titanium-silicon alloy. The addition resulted in an increase in hardness, transverse strength, transverse resilience, impact value and tensile strength.

22. *Titanium-Copper-Chromium*. Irons Nos. 37 and 38 show the effect of an addition of titanium, copper and chromium. Hardness was increased as was transverse strength, transverse resilience, tensile strength and impact resistance.

IMPACT TESTS OF THE CUPOLA AND ELECTRIC FURNACE IRONS COMPARED

23. *Cupola Irons*—In general, the transverse resilience of the cupola alloy irons show a fairly good relation to the impact

resistance as measured both by repeated drop tests on unmachined bars and by single blow tests on machined bars. The single blow test on machined bars appears to be more sensitive and more nearly in agreement with the transverse resilience.

24. *Electric Furnace Irons*—In the case of the electric furnace irons that were gray as cast, the austenitic iron No. E17 showed the highest impact resistance. No. E18 iron of the same type but with chromium increased to 3.81 per cent shows about half the impact resistance of the No. E17 iron. The increased chromium resulted in higher hardness, lower transverse load and deflection, lower transverse resilience with almost no change in tensile strength.

25. Aside from the austenitic irons, it appears that the very low carbon irons are less shock resistant than those of medium carbon content. The least shock resistant was the very high carbon iron No. E16. This type of iron has good thermal shock resistance and is of interest for that reason. The irons of highest impact resistance were those that were cast white and annealed (Nos. E19 and E20).

General Observations on Impact Results

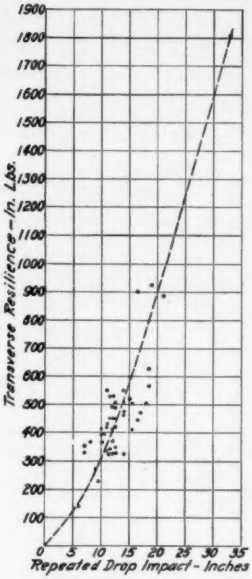
26. The transverse resilience values of all the irons were plotted against repeated drop impact tests and are shown in Fig. 3. The curve drawn in the figure is one giving an approximate average relation for the two values. The same was done for the single blow impact tests made and the results are shown in Fig. 4.

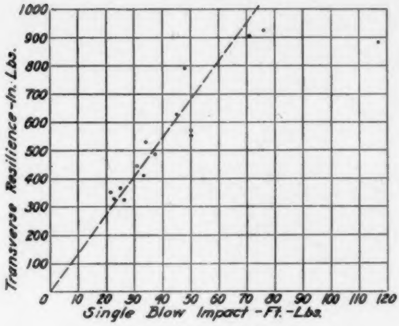
27. Fig. 5 shows repeated drop impact tests plotted against single blow impact tests. Fig. 6 shows transverse strength plotted against tensile strength. This curve is given for the reason that many times it is desired to know the approximate tensile strength of an iron for which the transverse strength is known.

Microstructures

28. The microstructure of cupola irons No. 1 and 10, are shown in Fig. 7. These two irons tested lowest and highest respectively in both the repeated drop and single blow impact tests with the exception of the very high phosphorus iron No. 20.

29. The matrix of cupola iron No. 1 is pearlitic with some steadite and the graphite flakes are interlocking and of medium





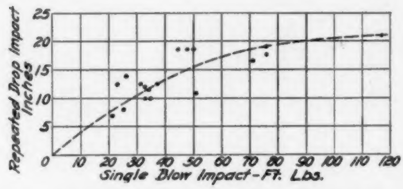


FIG. 3—LEFT—RELATION BETWEEN TRANSVERSE RESILIENCE AND REPEATED DROP IMPACT TESTS. FIG. 4—RIGHT (ABOVE)—RELATION BETWEEN TRANSVERSE RESILIENCE AND SINGLE BLOW IMPACT TESTS. FIG. 5—RIGHT (BELOW)—RELATION BETWEEN REPEATED DROP IMPACT TESTS AND SINGLE BLOW IMPACT TESTS ON GRAY IRONS.

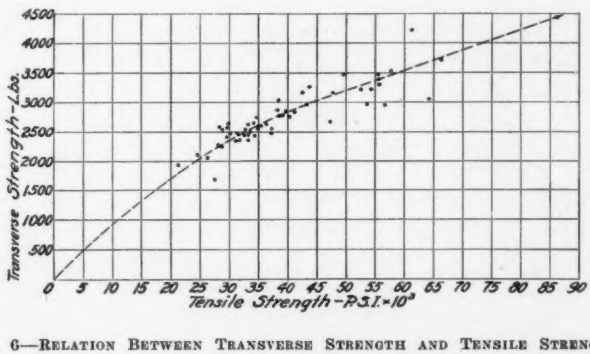


FIG. 6—RELATION BETWEEN TRANSVERSE STRENGTH AND TENSILE STRENGTH.

size. The matrix of cupola iron No. 10 is composed of very fine pearlite containing a few small cementite areas. The graphite flakes of this iron are rather long, thin and somewhat interlocking.

30. The microstructure of electric furnace irons Nos. E15 and E20 are shown in Fig. 8. Electric furnace iron No. E15

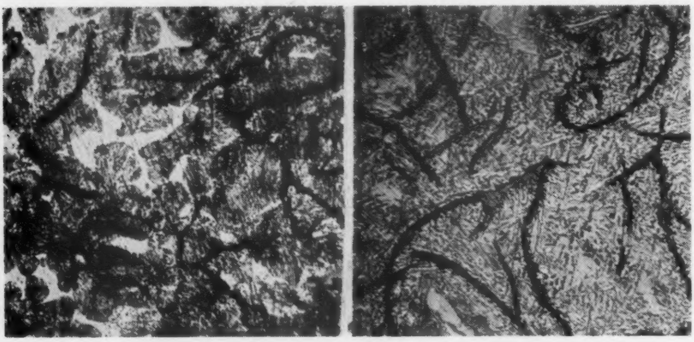


FIG. 7—MICROSTRUCTURE OF (A) CUPOLA IRON NO. 1, ETCHED WITH 2 PER CENT NITAL, 250x; (B) CUPOLA IRON NO. 10, ETCHED WITH 2 PER CENT NITAL, 250x.

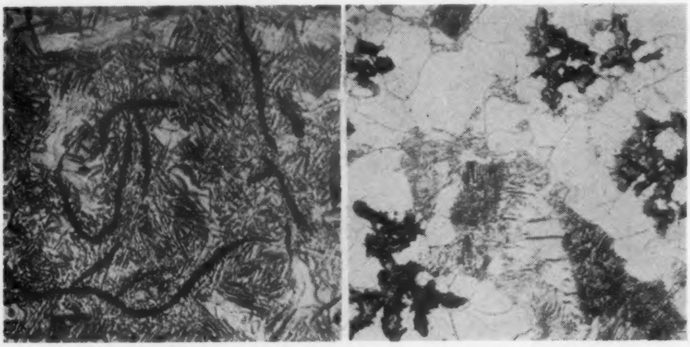


FIG. 8—MICROSTRUCTURE OF (A) ELECTRIC FURNACE IRON NO. E15, ETCHED WITH 2 PER CENT NITAL, 250x; AND (B) ELECTRIC FURNACE IRON NO. E20, ETCHED WITH 2 PER CENT NITAL, 250x.

tested highest of this group, with the exception of the austenitic irons and irons that were white as cast. No. E20 iron was cast white and annealed to produce a gray iron that showed the highest impact value of all those tested.

31. The matrix of electric furnace iron No. E15 is sorbitic-martensitic and contains some small cementite areas. The graphite flakes are thin and discontinuous. The matrix of electric furnace

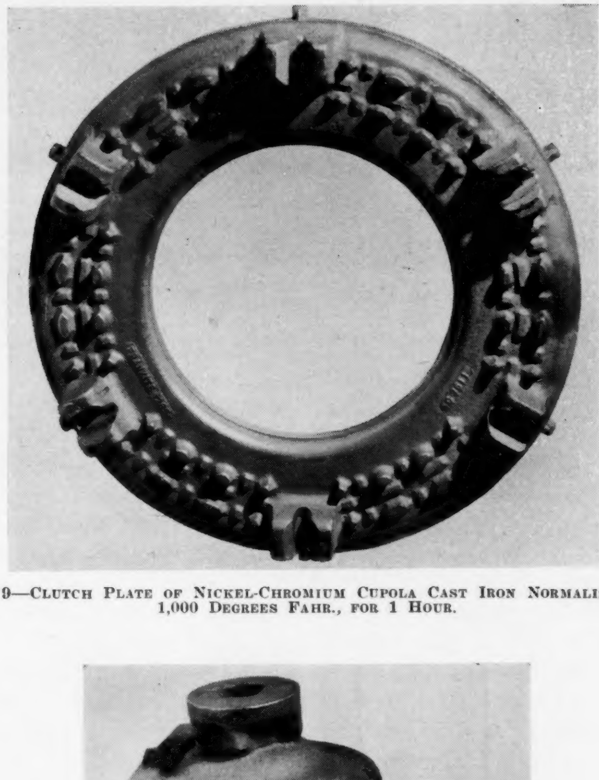


FIG. 9—CLUTCH PLATE OF NICKEL-CHROMIUM CUPOLA CAST IRON NORMALIZED AT 1,000 DEGREES FAHR., FOR 1 HOUR.

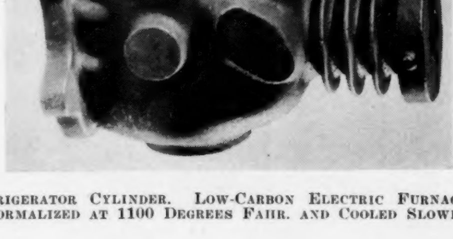


FIG. 10—REFRIGERATOR CYLINDER. LOW-CARBON ELECTRIC FURNACE CAST IRON, NORMALIZED AT 1100 DEGREES FAHR. AND COOLED SLOWLY.

iron No. E20 contains ferrite, pearlite and sorbite. The graphite particles are small and, while of irregular shape, are not of the flake variety.

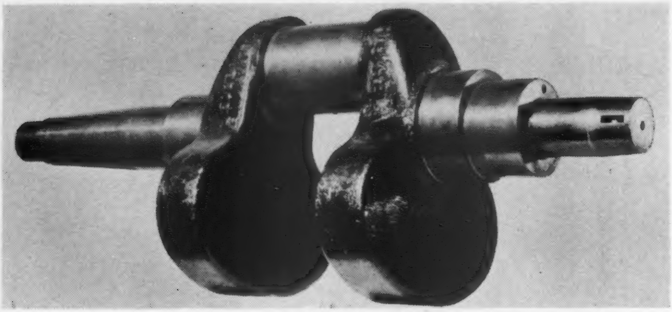


FIG. 11—CRANKSHAFT OF NICKEL-MOLYBDENUM ELECTRIC FURNACE IRON, ANNEALED 1150 TO 1170 DEGREES FAHR. FOR 1 HOUR. BHN 250.

32. Fig. 9 shows a clutch plate casting for truck service. It was made from cupola iron No. 35, a nickel-chromium iron. The casting was normalized at 1000 degs. Fahr. for 1 hour. Fig. 10 shows a refrigerator cylinder made from low carbon electric furnace iron similar to electric furnace iron No. E1 shown in Table 3. This casting was normalized at 1100 degs. Fahr. Fig. 11 shows a compressor crankshaft made from nickel-molybdenum electric furname iron similar to No. E9 in Table 3. This casting was annealed at 1150 degs. Fahr. for 1 hour to a Brinell hardness of 250. Fig. 12 shows a pitman casting made from non-alloy electric furnace iron similar to No. E20 (except no alloys) in Table 3. This casting was cast white and annealed as per note 11 of Table 3.

SUMMARY

33. The test results given in this paper indicate that, in the case of irons cast gray, and omitting austenitic iron, fairly high carbon nickel-molybdenum irons that may contain some chromium have good impact resisting properties. The highest impact resistance is obtained on irons that are cast white and converted to

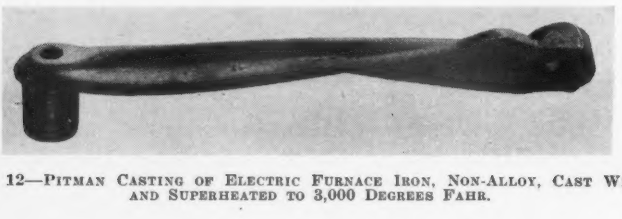


FIG. 12—PITMAN CASTING OF ELECTRIC FURNACE IRON, NON-ALLOY, CAST WHITE AND SUPERHEATED TO 3,000 DEGREES FAHR.

gray irons by annealing. Austenitic irons of low hardness have high impact resistance.

34. Transverse resilience correlates fairly closely with impact resistance and apparently the single blow impact test made on machined bars correlates with transverse resilience more closely than does the repeated drop test on unmachined bars.

ACKNOWLEDGMENTS

35. The author wishes to acknowledge the helpful cooperation of M. J. Gregory, Factory Manager, Foundry Division, Caterpillar Tractor Co., Peoria, Ill., for having made in his firm's laboratories all the single blow impact tests and the cooperation of H. Bornstein. Director of Laboratories, Deere and Co., Moline, Ill., for having had made all the repeated drop tests.

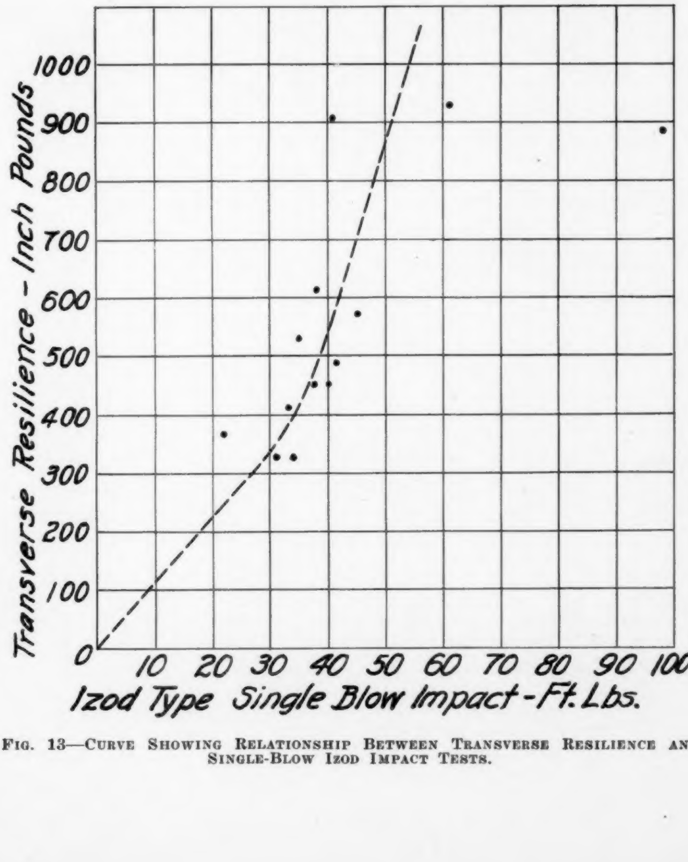


FIG. 13—CURVE SHOWING RELATIONSHIP BETWEEN TRANSVERSE RESILIENCE AND SINGLE-BLOW IZOD IMPACT TESTS.

Supplementary Data on Single Blow Impact Tests on Izod Machine

36. Since the above paper was prepared additional data have been secured which it is believed will prove of interest.

37. Fourteen of the irons were tested in an Izod machine by the International Nickel Co. Laboratories. The fourteen irons tested included the ten cupola irons given in Table No. 5 and four of the electric furnace irons.

38. The bars were tested in the unmachined condition and were broken 3.0 inches above the supports in a cantilever type of break. The capacity of the machine was 120 ft.-lb. The data obtained are given in Table 6 (page 18) in which are included data given in Table 5 for comparison.

39. The transverse resilience was plotted against the Izod

Table 6

TRANSVERSE RESILIENCE, REPEATED DROP IMPACT, CHARPY TYPE SINGLE BLOW IMPACT AND IZOD TYPE SINGLE BLOW IMPACT

Iron No.	Transverse Resilience in.-lb.	Repeated Drop Impact, in.	Charpy Type Single Blow Impact, ft.-lbs.	Izod Type Single Blow Impact, ft.-lb.
CUPOLA IRONS				
1	363	8.0	25.0	22.0
2	410	10.0	33.0	33.0
3	489	12.5	37.0	41.0
4	444	12.5	31.5	37.0
5	533	11.5	34.0	35.0
8	454	12.0	33.0	40.0
9	626	18.5	44.5	38.0
10	927	19.0	76.0	61.0
11	563	18.5	50.0	45.0
12	906	16.5	71.0	41.0
ELECTRIC FURNACE IRONS				
E6	335	12.5	23.0	31.0
E7	322	14.0	26.0	34.0
E17	882	21.0	117.0	98.0
E20	3082	[1]	[2]	[3]

[1] Did not break at capacity of machine of 40 in.
[2] Did not break at capacity of machine of 125 ft.-lb.
[3] Did not break at capacity of machine of 120 ft.-lb.

type single blow impact tests and an average curve drawn to show relationship between the two properties. This is shown in Figure 13. The same thing was done for repeated drop impact and Izod type single blow impact and the curve obtained is shown in Fig. 15. Fig. 14 shows the curve obtained by plotting Charpy type single blow impact against Izod type single blow impact. The relationship shown in Fig. 14 is particularly good.

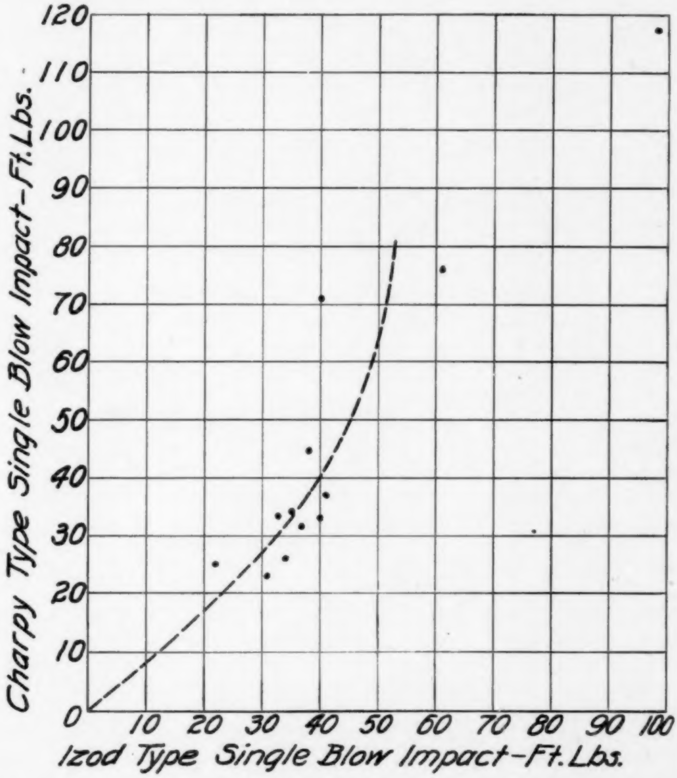


FIG. 14—RELATION BETWEEN SINGLE-BLOW CHARPY AND SINGLE-BLOW IZOD IMPACT TESTS.

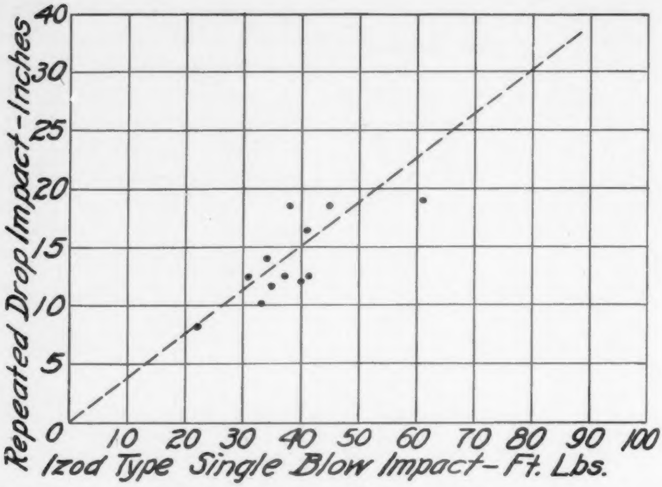


FIG. 15.—CURVE SHOWING RELATIONSHIP BETWEEN REPEATED-DROP IMPACT AND SINGLE-BLOW IZOD IMPACT TESTS.

DISCUSSION

DR. H. A. SCHWARTZ[1] *(Written Discussion)*: The writer desires to offer comment on only a single feature of Mr. Phillips' very interesting paper. This comment concerns itself with the general question of the comparison of repeated drop and single blow impact tests.

The conversion factor in the last line of page 126 of Mr. Phillips' paper evaluates the energy of the last of the series of repeated drops and not the total energy which has been absorbed by the specimen from the entire series of drops. There can be no objection to the author's correlating, for purposes of record, the single blow impact value with the repeated drop impact value in terms of the height of fall of the last of the repeated drops as he has done in the lower right hand diagram of Fig. 3. As a matter of logic, however, it would seem better to have computed the aggregate or accumulated energy of the repeated drop test and used this for the ordinate. This has been done in the attached Fig. 16 by recalculation of the values given in the author's Table 5.

It is to be pointed out that the fractional values of Table 5 are also open to some misconception; presumably they represent the average of two tests differing by an odd number of inches. Assuming that they differ by one inch so that a value reported as 12½ in. represents one repeated drop terminating at 13 inches and another at 12 inches, the corresponding energies can be averaged for these two heights of fall.

[1] Manager of Research, National Malleable and Steel Castings Co., Cleveland, O.

This has been done and represented by open circles in the present writer's Fig. 16. For comparison, there is shown as a solid circle the corresponding value if the last drop had actually been from the several fractional heights shown.

The writer desires to point out that although the results still scatter rather badly, a general trend line through them is considerably straighter than in the author's Fig. 3. It will be observed that in Fig. 3, in spite of the fact that the specimen subjected to repeated drop was somewhat larger in diameter than that subjected to single blow impact, yet if we evaluate the energy as suggested by the author, the metal breaks much more readily under the repeated impact than under single blow impact. One can not say how much of the energy of the last drop was used up in breaking the specimen. Any difference between that energy and the single blow energy represents the accumulated destructive effect of the preceding blows. On the other hand, in the present writer's Fig. 16, the energy corresponding with the accumulated impacts is some four or five times as great as the energy of the single blow which breaks the specimen. The difference might be accounted for by differences in size of specimen and still more by the fact that some portion of each of the successive drops is not absorbed by the specimen but returned elastically. In view of the uncertainty as to what fraction of the last blow is actually required for rupture, any of the points of the writer's figure may require lowering by an unknown amount not greater than the energy of the last blow.

These comments are offered not by way of criticism of the original paper but as a matter of further elucidation.

MR. PHILLIPS: The constructive criticism given by Dr. Schwartz is greatly appreciated by the author. The most important point raised by

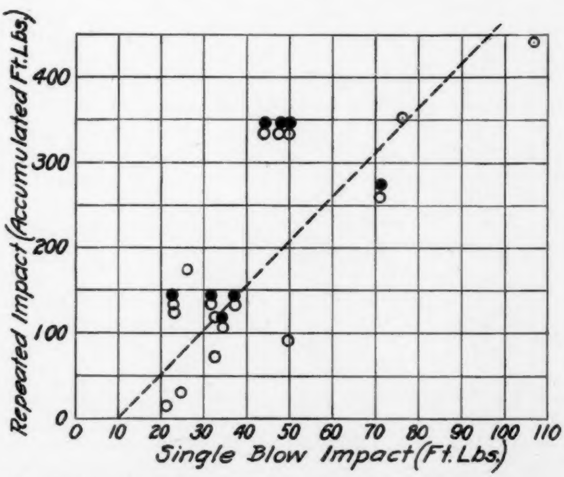


FIG. 16—GRAPH SHOWING SINGLE BLOW IMPACT VALUES CORRELATED WITH VALUES FOR ACCUMULATED ENERGY OF THE REPEATED DROP TEST.

him is one of interpretation of the results of the repeated blow impact test.

It is well known that it is practically impossible to determine the total energy absorbed by the specimen being tested when subjected to repeated drop tests in which the energy is progressively increased. At the start of the test, when the energy of the falling hammer is due principally to its mass and in small part only to its velocity, the energy absorbed by the specimen may be a high percentage of the total energy in the falling hammer. As the velocity factor increases with increasing height of drop the energy absorbed by the specimen probably decreases so that it becomes a question whether to use the energy of the final, breaking drop or the accumulated energies of all the drops as an index of shock resistance. In either case the absolute value of shock resistance is not known.

If we take the data given for iron No. 10 in Table 5 of the paper and evaluate all the date in the same units of foot-pounds per cubic inch we obtain the following:

Transverse Resilience	3.79 ft.-lbs. per cubic inch.
Repeated Drop—	
Using final drop only............	5.83 ft.-lbs. per cubic inch.
Using accumulated drops........	58.29 ft.-lbs. per cubic inch.
Single Blow	12.74 ft.-lbs. per cubic inch.

The data given above show the futility of trying to make absolute comparisons between the results obtained by different testing methods.

The writer feels that it makes no material difference as to what index is used as a measure of shock resistance under repeated drop tests. The need for a standardized impact test for cast iron is indicated in order that the results of various investigators may be directly compared.

DR. J. T. MACKENZIE[2] *(Submitted as Written Discussion)*: I was much interested in Mr. Phillips' paper as being the first extensive piece of work on impact on cast iron that has come out since the report of subcommittee XV of the A. S. T. M. Committee A-3 on Cast Iron in 1933. I therefore proceeded to work up some of Mr. Phillips' data on the basis of this impact report especially in the light of Fig. 17 on page 114 of the A. S. T. M. Proceedings, part 1 for 1933. We first read off the deflection at ½ load as best we could from the curve shown in Mr. Phillips' paper and by dividing obtained the ratio of the modulus of elasticity at ½ load to that at breaking point. From this, the curve for the ratio of the resilience at 80 per cent load after repeated loading to the first loading was read off from the line, obtained by least squares, which gives the equation:

$$R = -1.083 \text{ Log } E + 0.992.$$

The factors so obtained were used to correct the resilience to the values shown. These values, shown in Table 7, were then plotted against the drop test as given by Mr. Phillips and the results are shown in the attached Fig. 17. The line of Fig. 17 gives what would have been expected

[2] American Cast Iron Pipe Co., Birmingham, Ala.

Table 7

POINTS PLOTTED IN FIG. 17

Impact[1] Repeated Drop, in.	Corrected Resilience, in.-lb.	Impact[2] Repeated Drop, in.	Corrected Resilience, in.-lb.
8.0	305	12.5	438
10.0	365	12.5	317
12.5	435	12.0	327
12.5	400	17.0	453
11.5	480	14.0	470
12.5	443	12.5	322
15.0	442	14.0	319
12.0	436	14.0	527
18.5	564	15.5	480
19.0	805	14.0	490
18.5	524	14.0	468
16.5	788	18.0	445
10.5	361	16.5	340
12.5	422	10.3	342
11.5	324	18.5	760
9.0	235	7.0	341
12.5	401	21.0	458
11.5	306	11.0	425
9.5	218	33.0	1046
6.0	140	40.0	1171
11.5	317		
10.0	363		
12.0	345		
11.0	401		
15.5	378		
12.0	375		
12.0	459		
14.0	448		
12.0	402		
14.0	429		
12.5	403		
11.0	332		
13.0	413		
12.0	448		
10.5	378		
11.5	422		
11.0	382		
12.0	468		

[1] Values from Table 2.
[2] Values from Table 4.

from the results obtained on the machined bars used in the impact test. Since the committee had available three bars for transverse and nine bars for drop tests, I think the correlation is very good. It was also

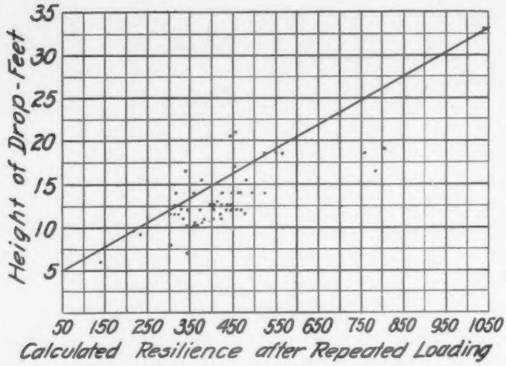


FIG. 17—RESULTS GIVEN IN THE PAPER RECALCULATED ON THE BASIS OF THE REPORT OF SUBCOMMITTEE XV OF A. S. T. M. COMMITTEE A-3 ON CAST IRON IN 1933. RESULTS ARE GIVEN IN TABLE 7.

interesting to plot the ratio of the planimetric resilience to the ordinary triangular resilience against the same ratio of the modulus of elasticity at ½ load to that at the ultimate. These results, shown in Table 8, are shown in Fig. 18 with the curve drawn in indicating the approximate values obtained from the impact report. With one or two exceptions the correlation is quite gratifying.

MR. PHILLIPS: The work done by Dr. MacKenzie in checking the results given in the paper against the results obtained, under his direction, by subcommittee XV of A. S. T. M. Committee A-3, is greatly appreciated by the author.

Dr. MacKenzie has pointed out a number of times in the past that the blows applied to a gray iron bar previous to the final breaking blow in a repeated drop test give a measure of the "set" or plastic deforma-

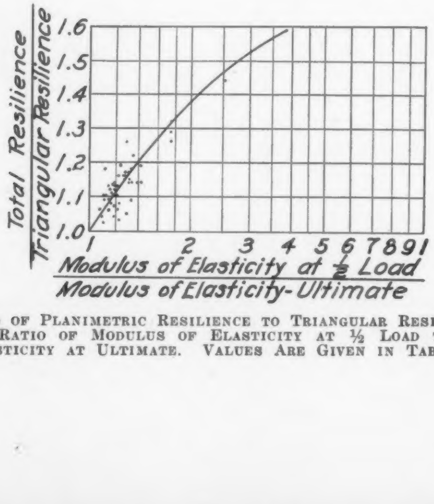


FIG. 18—RATIO OF PLANIMETRIC RESILIENCE TO TRIANGULAR RESILIENCE PLOTTED AGAINST THE RATIO OF MODULUS OF ELASTICITY AT ½ LOAD TO MODULUS OF ELASTICITY AT ULTIMATE. VALUES ARE GIVEN IN TABLE 8.

Table 8

POINTS PLOTTED IN FIG. 18

RT[1] / RA	Mod. Elas., ½ Load / Mod. Elas., Ult.	RT[2] / RA	Mod. Elas., ½ Load / Mod. Elas., Ult.
1.19	1.43	1.14	1.31
1.26	1.29	1.06	1.21
1.17	1.29	1.04	1.08
1.15	1.27	1.10	1.10
1.16	1.26	1.04	1.19
1.18	1.34	1.02	1.10
1.14	1.39	0.95	1.05
1.09	1.12	1.18	1.11
1.16	1.26	1.08	1.16
1.22	1.35	1.06	1.14
1.03	1.22	1.08	1.23
1.14	1.34	1.17	1.32
1.15	1.32	1.26	1.75
1.11	1.20	1.40	1.17
1.17	1.02	1.09	1.14
1.09	1.34	1.10	1.13
1.18	1.33	1.38	2.08
1.12	1.18	1.29	1.75
1.07	1.19	1.46	2.54
1.15	1.00	1.59	3.83
1.11	1.18		
1.13	1.21		
1.10	1.18		
1.13	1.19		
1.19	1.24		
1.16	1.23		
1.14	1.19		
1.11	1.17		
1.17	1.28		
1.14	1.19		
1.10	1.11		
1.06	1.07		
1.05	1.29		
1.14	1.42		
1.12	1.15		
1.13	1.19		
1.16	1.27		
1.13	1.14		

[1] Values from Table. 2.
[2] Values from Table 4.

tion. In other words, the blows remove the plastic property and the metal becomes practically elastic previous to failure in the repeated drop

test. For these reasons that Dr. MacKenzie has stated, I believe that the repeated drop test is more valuable than the single blow impact test.

It seems to the author that we might well have both a standardized repeated drop test and a standardized single blow impact test for gray cast iron. The use of the single blow type of impact test is prevalent in the engineering profession and many failures are of that character.

DR. J. T. MACKENZIE: Commenting largely on Dr. Schwartz' discussion, when we brought out the A. S. T. M. impact test report in 1933, we studied at considerable length the relation of the repeated drop and the single blow. It is apparent that the single blow impact parallels the resilience obtained in the same kind of a test specimen. Using a Charpy machine, it parallels quite closely the results from the transverse test. However, if anyone has ever made any set tests on cast iron, he will know that if he bends a bar, say with a 1,000 pound load, the second bending will not give the same deflection as the first. It will vary from that quite a little bit. If he keeps on bending the bar at increasing loads, he will get progressively greater plastic flow and the bar then has much less deflection.

Now the resilience in the transverse test is approximately proportional to the load times the deflection. But the curve has a pronounced curvature on the first loading. However, after these repeated loadings, it becomes almost a straight line. In fact, Pearce in England published a paper in which he showed that for all practical purposes, one could consider it a straight line.

The drop test, as we use it, is a set test plus an impact test on the bar at the time that it breaks. Now, if you take a soft iron and put it in a drop test machine, you can actually see the curvature on a six-inch span long before it breaks. One of the conclusions of the committee in the impact report was that, having measured the transverse resilience on a cast iron, the repeated drop test gave a pretty fair measure of the amount of set that you might expect. We worked out in the impact report the relationship between this set and the ratio of the modulus of elasticity of load to the modulus of elasticity at the breaking point. I took Mr. Phillips' results and, by working backwards from that relationship, I plotted his results on the same graph that the impact committee used, and the results, while more scattered than ours, did follow in general the same trend, a little bit below the line. One, however, must remember that the Impact Committee used machined test bars from which most of the surface imperfections were eliminated, so that you would expect the correlation to be much better in that document. Mr. Phillips used only two bars, whereas, the Committee had nine.

I think Mr. Phillips' paper shows that the drop test is a much more valuable form of impact test than the single blow type, just as the Committee concluded. You can get all there is in the single blow test out of the planimetric determination of the resilience in the transverse test provided you measure the deflection accurately.

W. H. SPENCER:[3] Most of the experience I have had was on the A. S. T. M. work. However, I might say that using the total inch pounds for all drops to give a value for cast iron might give misleading information to some engineers and to some foundrymen, because all the blows do not affect the metal. The lower drops are effective on some metals but their feeble energy is not absorbed at all by others. Adding in energy which is not absorbed might give misleading high values for the impact strength of the metal.

H. R. CLARKE:[4] Has Mr. Phillips any way to account for the differences in the tensile properties of bars of almost identical analyses? For instance, in his paper bars No. 2 and No. 4, Table 2, show a drop test of 10 and 12.5, and tensile strength of 24,610 and 32,910 lb. per sq. in. respectively. Then when we look at bar No. 25, an outstanding iron without molybdenum, it shows a drop test of 15.5, better than any of the irons with molybdenum. Yet the average of the irons with molybdenum show up higher than the general average. It seems to me that this is a very important point. We have these alloys and these various analyses and the chances are that we will get some very strong irons and very good physical properties, if we use them, but we never can tell.

Can anyone tell us why some of these irons with the same analysis have excellent physical properties and some very poor physical properties? What I am getting at is that we are a long way from the actual production of reliable castings. We have a very good chance of making strong castings if we will reduce the carbon and increase the nickel and chromium and molybdenum, but we never can be sure. If we could find out the difference between these particular irons, we might be able to make some real progress. Mr. Phillips' data forces our attention to what I believe to be the fact that the unknown quantities in cast iron are as effective as the quantities we now know.

MR. PHILLIPS: I am not sure which irons Mr. Clarke refers to, but I presume that he means cupola irons Nos. 2, 4 and 15. No. 2 iron is one of the 10 per cent steel-mix irons while No. 4 is one of the 23 per cent steel-mix irons. No. 2 iron has 0.30 per cent higher silicon and 0.10 per cent lower combined carbon than does No. 4 iron. I believe that these differences account for the higher tensile strength of the No. 4 iron as compared to No. 2 iron. No. 15 iron is the one that I mentioned as having higher impact resistance than a large number of irons of that same analysis, some of which are included in this paper. An exhaustive microscopic study of all the irons was not made. It may be that the answer lies in the structure of this particular iron.

MR. CLARKE: I would like to ask if all the cupola irons were taken at exactly the same time during the heat? The reason that I asked that question is that I have observed the first iron from a heat has an open grain. Further along in the heat, the grain normally will close. Did Mr. Phillips observe any difference in the impact value of the open-grain metal as compared with the close-grain metal?

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[3] Sealed Power Corp., Muskegon, Mich.

[4] Sloss-Sheffield Steel and Iron Co., Chicago.

MR. PHILLIPS: The test bars were all poured with metal from full trolley ladles the same distance from the cupola. The temperatures of the irons coming from the cupola were all within normal variation of about 2800-2835 degrees Fahr.

With the one exception noted in the paper, all bars were poured with steel-mix metals. Our normal routine procedure was to melt regular soft gray iron with no steel in the mixture for the first hour or more, depending on the amount needed by the foundry, then to switch to 23 per cent steel-mix metal. There was no change in the grain of the metal during the heat. An increasing closeness of grain with accompanying deeper chill in chill test bars, would normally mean a decrease in total carbon or silicon or both and possibly oxidation. In other words, we would say that that cupola operation under such circumstances was decidedly not uniform.

Progress in the Production of Cast Iron for Locomotive Parts

By A. Reyburn,* Montreal, Canada

Abstract

Following the World War, Canadian railroads were rehabilitated and larger and heavier motive power was introduced. Failures of locomotive cylinders in this heavier equipment, focused attention on cast iron and in this paper, the author tells what has been done by one Canadian railroad to improve the quality of the cast iron in its locomotives. The author outlines the types of irons used for such parts as cylinders, cylinder liners, valve bushings, pistons, bullrings and packing-rings together with a general summary of the molding and coremaking practice for cylinders. The use of nickel and nickel-chromium cast irons has, in several instances, increased life of parts and saved considerable cost to the railroads.

1. The object of this paper is to tell the story of the production of high strength cast iron for locomotive cylinders and related parts such as liners, valve bushings, piston bullrings, packing rings, etc., from the viewpoint of the man in the foundry.

2. To get a better picture of this subject, it is necessary to review briefly the developments in railroad transportation since the close of the World War. The close of the war found Canadian railways in need of general rehabilitation and demands were being made for better transportation, both by the travelling public and by shippers of freight. Greater speed and heavier loading brought about the development of larger and more powerful motive power.

3. In the interests of efficiency and operating economy, these more powerful locomotives were made to haul trains to the full extent of their rated haulage capacity and for longer distances than had been the case formerly. The best efforts of the mechan-

* Foundry and Pattern Foreman, Canadian National Railways.

Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

ical engineer were put into design, the steelmakers met the closest specifications for boiler plate, staybolt steel, steel billets, main frames and many other important castings. The latest equipment for efficient boiler operation such as superheaters, feed water heaters, stokers, etc., were applied. Thus, the modern locomotive was evolved from the small machine of a score or more years ago to a mighty throbbing giant.

CYLINDERS FAIL

4. In contrast to all the magnificent engineering achievements in locomotive construction, the cylinders of these machines were still being made in what is known as plain cast iron. It is common knowledge that in the older type locomotives, cylinders were good for the life of the engine failing an accident or collision. The advent of higher boiler pressures, superheated steam with its increased temperature in the cylinders, greater tractive effort at higher speeds and especially a climate of extremes, sometimes as low as —60 degrees Fahr., very quickly demonstrated that plain cast iron could not give the performance demanded.

5. Cylinder failures in new locomotives began to occur all too frequently and demanded serious attention of the mechanical staff. In 1927 it was almost decided to go to cast steel cylinders, but the expense of redesigning castings, making all new patterns, plus the uncertainty of the success of cast steel for this job as well as the increased cost, caused the chief mechanical officers to enquire into the possibility of making a cast iron cylinder of sufficiently increased tensile strength to withstand the severe duty now demanded.

6. The latest developments in the production of high strength cast irons under the committees on Cast Iron of the A.F.A. and A.S.T.M. having been carefully reviewed by the chemist and metallurgist, it was decided to make some test cylinders and special castings using various percentages of steel scrap, pig iron, cast scrap, car wheel scrap with and without alloy additions. It is not necessary to detail the results obtained other than to state that it was established definitely that an iron could be produced which would give a tensile strength of over 40,000 lb. per sq. in. and even this could be exceeded if desirable, although it was felt that an iron of 40,000 lb. per sq. in. would be easier to produce if it would meet the requirements.

7. Service tests on locomotives proved satisfactory after some

months and therefore a new specification was put into effect and from 1929 all cylinders have been made to the new specification. Analysis is as follows:

Silicon, per cent—0.80 to 1.10 (0.90 Desired).
Sulphur, per cent—0.11 Max.
Manganese, per cent—0.80 to 1.00 (1.00 Desired).
Phosphorus, per cent—0.20 Max.
Total Carbon, per cent—3.00 to 3.20.
Nickel, per cent—0.75 Min.

Physical Properties

Load, lb.—4,000.
Deflection, in.—0.13 on 1¼-in. Diameter bar, 12-in. centers.
Brinell Hardness—240.

A microphotograph of the structure of the nickel cast iron is shown in Fig. 1.

Cupola Operation

8. Charges are 1500 lb. melted in a 54-in. cupola using a centrifugal blower with automatic blast gate control. Cupola charges are weighed and charged mechanically by the "wishbone" system. Bed coke is charged 42 in. above tuyeres as this height has been determined best after experiment. Intermediate charges are 200 lb. of coke. Iron charges consist of 30 per cent pig iron, 60 per cent steel rail ends, 10 per cent scrap car wheels. Ferromanganese is charged into cupola. Limestone is used as a flux.

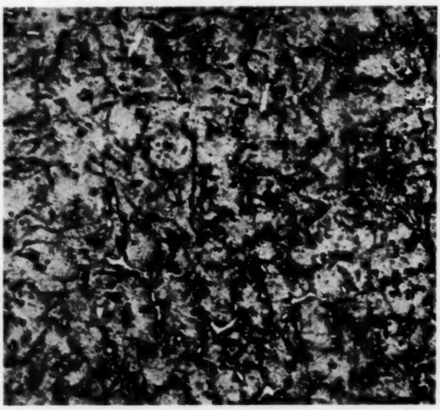

Fig. 1—Micrograph of Nickel Cast Iron Used for Locomotive Cylinder Castings.

Iron comes down rapidly and is tapped at rated capacity of cupola at definite tapping intervals to get fairly close carbon control. Temperature at the spout is 2700 degrees Fahr. according to an optical pyrometer, actual reading, no correction.

9. Metal is tapped into a 10-ton ladle and after the required amount is tapped, it is allowed to stand until the temperature reading on optical pyrometer is about 2400 degrees Fahr. (without correction) at the top of the metal in the ladle. This gives a pour-

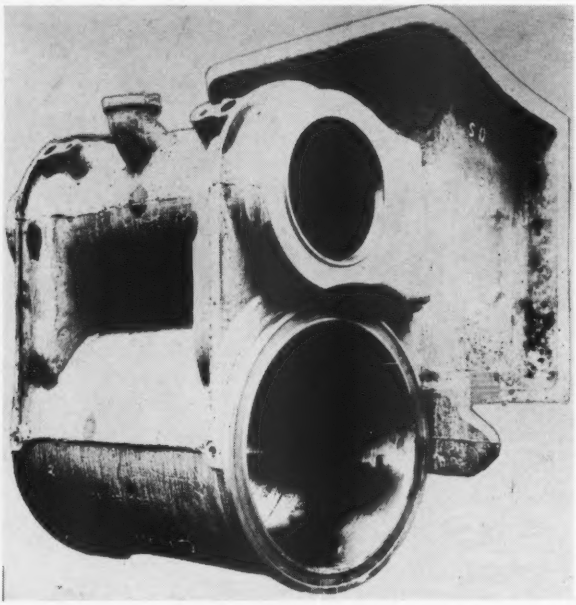

FIG. 2—LOCOMOTIVE CYLINDER CASTING. WEIGHT OF ROUGH CASTING, 10,250 LB.

ing temperature of 2500 degrees Fahr. which has been found by experiment to be the best pouring temperature for these castings, which weigh on an average 10,000 lb. each. (Fig. 2) It has been noted that there is a drop of 100 to 150 degrees Fahr. from the ingoing metal at the lip of ladle to that which flows through the risers at the far side of the mold from the pouring head. It is this fact which has governed the pouring temperature for the ensuring of sound castings, as the risers are placed on the barrel of the cylinder which must have good metal and the added precaution of flowing metal through risers is taken.

10. Where a single sprue and runner with two or three in gates served to pour plain iron cylinders, it was necessary to change this practice for iron with high percentages of steel. Now two sprues and six "in" gates are used, one sprue and three in-gates on each side of saddle bolting flanges. Both sprues are connected by one pouring head as shown in Fig. 3. This gating method has been found satisfactory and allows an even flow of metal into mold.

11. Cylinder castings which are urgently required are shaken out 12 to 18 hours after pouring, but when time permits, it is customary to allow them to cool in the mold for two or three days.

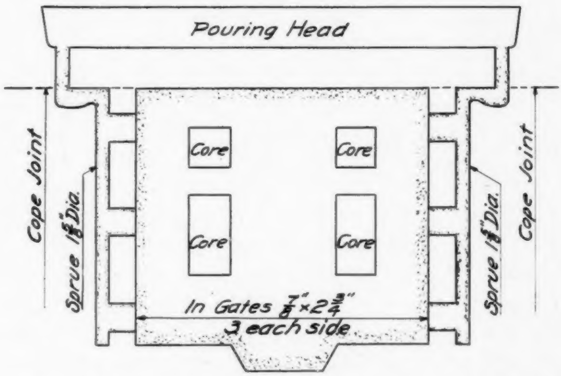

FIG. 3—SKETCH SHOWING METHOD OF GATING LOCOMOTIVE CYLINDER CASTING.

12. Molds are made in special flasks and dried in electric ovens. Cores are made from silica sand bonded with oil and corn flour binders. This type of core is used to ensure strength and to withstand pouring temperature of metal and also to facilitate easy removal from castings. Tinned wrought iron chaplets are used to guard against leaks as other kinds formerly gave trouble through failure to fuse when cast. Five risers are used on every casting, two on frame bolting flange and three on barrel over cylinder cock bosses.

13. Castings are cleaned by opening holes in cavities and then are sent to the sandblast room for removal of the bulk of sand. Then the core arbors are broken out and the castings chipped. A final sandblasting operation cleans all sand from exhaust ports and casting is then delivered to machine shop or stock yard.

PARTS FAILURES REDUCED

14. The failure of plain cast iron to give satisfactory service on such castings as cylinder heads was another problem which caused many locomotive failures and train delays. By the use of this stronger iron, these failures from metal causes have ceased and the renewal of cylinder heads has been reduced to ordinary replacement for mechanical reasons, such as having reached condemning limits.

15. The life of cylinder liners, valve bushings, pistons, bull-rings and packing-rings made of plain cast iron was of such short duration that a better wearing iron was necessary in the interest of economical operation. After many experiments over a number of months in the making of piston-ring tub castings, it was decided to make the previously mentioned cylinder iron containing approximately 1.0 per cent nickel the standard specification for these castings. Service results have justified this decision and the life of piston rings commonly is 90,000 to 100,000 miles.

16. When it is considered that cylinder liners vary in diameter from 20 to 29 in., having a length of 42 in. with a wall thickness of 3/4 in. when machined, foundrymen will readily admit that this is a job in which molding practice and casting technique must be correct. These castings are made vertically in dry sand molds and top poured through five or six pop gates, according to diameter, and metal is poured at the temperature of 2500 degrees Fahr., which has been determined by experiment. Machineability is very good and a very fine finish is obtained.

LINER LIFE INCREASED

17. Considerable increase in life of these liners has effected economy in cost of locomotive repairs. The same results have been obtained with the other castings mentioned previously which are component parts of the locomotive cylinder. Fig. 4 shows a group of these parts.

18. Another application of this iron which is giving excellent results is the locomotive driving axle box. In 1931, a series of 20 freight locomotives were built and equipped with nickel-iron driving boxes throughout, with the exception of the main wheels. These locomotives have been in constant service since that time and no failures have been reported to date. This application has now been adopted as standard for renewals on similar classes of locomotives.

19. The use of nickel-chromium grate-bars for locomotives has replaced cast steel grate-bars at a considerable economy. By the addition of 1.50 to 1.60 per cent nickel and 0.60 per cent chromium to a correct base metal, it has been established over a lengthy period of service that the trouble experienced with growth of plain cast iron bars has been eliminated (Figs. 5 and 6). The length of service obtained from these alloyed grate bars is at least

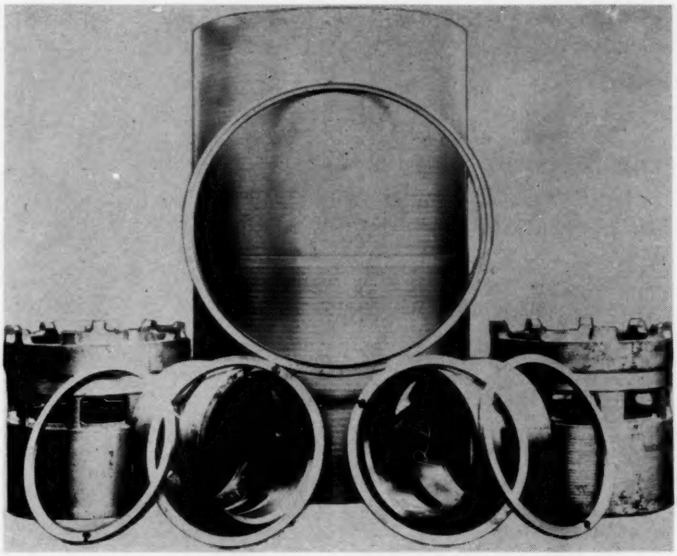

Fig. 4—Group of Locomotive Castings Showing Cylinder Bushing, Valve Bushings, Piston Ring and Valve Rings. (Marks Seen on the Castings Are Not Defects, But Are Tar Picked-up in Rolling the Casting into Position.)

equal to the alloyed cast steel bars and have the added advantage of remaining flat where the steel bars warped badly and caused loss of coal into ashpans. The difference in cost is readily seen to favor the alloyed cast iron bar.

20. A device called the "radial buffer" which is applied between engine and tender is comprised of several steel castings. This device allows free movement of enginers on curves and takes the shock in starting and stopping trains. The stationary block which is fastened to the footplate is subject to an excessive amount of wear. As the maintaining of these blocks is very expensive, it was decided to apply two or three of these made of nickel cast

iron and test them out. This was done to two types of locomotives in 1932 and their operation has been carefully checked.

21. The results obtained have been fully satisfactory and to date these blocks are still in service. The main feature in this application of the alloyed cast iron is that while it withstands the buffing shocks, it also gives a much better wearing combination of steel working against cast iron. The steel to steel application wears out rapidly, hindering the sliding action necessary for efficient buffing, whereas the steel to cast iron retains the original contour of the face and provides a smooth buffing action for a

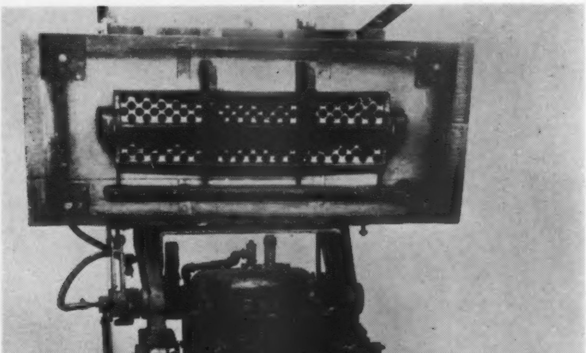

FIG. 5—LOCOMOTIVE GRATE BARS. METHOD OF MOLDING GRATE BARS.

long period of service. When the steel block wears, it is an expensive job to build up to the original contour by electric arc welding. When the cast iron block has reached condemning limits, it is much cheaper to apply a new block.

22. As a result of the tests obtained, it has now been decided to adopt this practice and more efficient operation should result at a considerable economy to the railroad. This development in the use of alloyed cast iron is considered worthy of special notice.

Conclusion

23. From the foregoing, the conclusion is reached that the

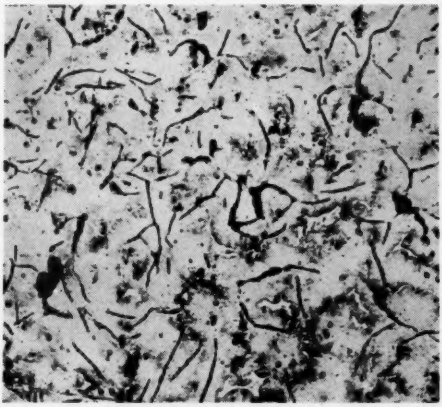

Fig. 6—Micrograph of Nickel-Chromium Cast Iron Used for Grate Bars.

development of high-strength alloyed cast iron for use in railroad castings has filled a long felt need and the Canadian National Railways are proud to have been in the forefront of this development.

24. Acknowledgments are due to the management of the Canadian National Railways for their readiness to adopt these progressive methods for the improvement of cast iron and for the freedom extended to the foundry staffs both at Montreal and Winnipeg in the working out of these problems. It is also fitting that due recognition be given to the pioneer work done by F. H. Williams, assistant test engineer, Montreal, in calling attention to what could be done to strengthen cast iron and its improvement in wearing qualities by the judicious use of small amounts of alloys.

25. In the preparation of this paper the writer wishes also to acknowledge the kindness of J. Roberts, chief of motive power and car equipment, Canadian National Railways, Montreal, for the permission granted and also the help of Robert Job, consulting chemist, in giving helpful suggestions and some historical data. The photographs kindly supplied by F. H. Williams also are gratefully acknowledged.

DISCUSSION

D. H. MELOCHE:[1] I have a query in reference to paragraph 16 of Mr. Reyburn's paper, where it says: "When it is considered that cylinder liners vary in diameter from 20 to 29 in., having a length of 42 in. with a wall thickness of ¾ in. when machined. * * * Machinability is very good and a very fine finish is obtained." I would like to know how the total carbon at the top of this liner varies from the bottom, which, after all, is in direct relation to the strength in the top and the bottom.

H. J. ROAST:[2] I note in paragraph 6 the statement that this investigation was started on the basis of developments in the production of high strength cast irons under the committees on Cast Iron of the A.F.A., supplemented by the A.S.T.M. It is rarely that investigations of that kind, it seems to me, over an experience of some years, have such satisfactory results as have been outlined by the author of this paper. My thought was that perhaps we shouldn't let the matter pass without drawing attention to the excellent work that had been done and the fact that our own publications formed the basis upon which it was built.

MR. REYBURN: In connection with the question regarding paragraph 16, no work has been done of that nature to determine whether there was a difference in total carbon at the bottom and at the top. The only thing we do to insure soundness in that casting is to cast it about four or five inches longer than the usual length and cut off the head. It is necessary, as you know, for a boring operation, to have at least two or three inches for holding such a casting in the jaws of the boring mill, and an extra one or two inches is immaterial providing you are getting a good casting.

It is also true that these castings are stock castings and may vary in length for different classes of locomotives, of the same diameter, so that we have not gone into any investigation as to the condition of one end of the casting as compared with the other, as long as it is sound. I might say that these castings have given considerably increased life over anything that we ever had before.

[1] Chief Metallurgist, American Radiator Co., Detroit, Mich.
[2] Technical Advisor, Canadian Bronze Co., Ltd., Montreal, P. Q., Canada.

Industrial Health Hazards and Employer Responsibility

By Dr. W. J. McConnell,* New York, N. Y.

The recognition of the importance of giving greater attention, on the part of foundry executives to consideration of the employers' responsibilities in overcoming industrial health hazards which may be connected with foundry operations, prompted the holding of a special session on this subject at the 1935 Toronto convention. This paper by Dr. McConnell, one of two presented at this session, discussing some of the medical aspects, outlines foundry hazards and presents some suggestions for control programs. Discussion of this paper is combined with that of the second paper by D. E. Cummings and may be found beginning on page 180.

A great deal has been heard recently, particularly in the State of New York, about the cost of compensation insurance for the protection against occupational diseases. Various estimates of such costs range from less than 1 to more than 10 per cent of the payroll. Irrespective of what rate will be set in the beginning, eventually the determining factor of cost will depend upon the efficiency of measures used for the protection of workers. Neglect to provide protective measures may prove extremely costly. Control will reduce the cost to an insignificant expense.

Health Maintenance Economically Necessary

With the many demands made upon industry for employee compensation, either through legislative or civil action, following injury to health arising out of, or alleged to arise out of, and during the course of employment, the maintenance of the health of any working force has become, from an economic viewpoint alone, a practical necessity.

During recent years, the responsibility of the employer has steadily broadened, due chiefly to the fact that the capacity for control of health conditions in industry lies almost entirely in his hands, and the employer has found it to be good business to reduce to a minimum the money losses due to sickness among workers. He has done this by providing a program consisting largely of health supervision and education, plant hygiene and safety engineering.

* Assistant Medical Director and Director, Industrial Health Section, Metropolitan Life Insurance Co.

BASIS OF HEALTH CONTROL

The essential basis of health control in industry is the physical examination. Without knowledge of the physical condition of the individual whose health is to be conserved or bettered, it is difficult, if not futile, to develop the facilities required for his care. It is also true that only by regular medical examinations over a period of years can a reliable opinion be formed regarding the effectiveness of preventive measures used to prevent the occurrence of occupational diseases.

REASONS FOR OCCURRENCE

The question may be asked, "Why do occupational diseases occur?" Many causes might be cited, chief among which are two:

> First, occupational diseases occur because of the employment of poor risks, or the failure to select workers physically and mentally capable of giving reasonably continuous service. In the selection of workers, consideration also must be given to the possibility of the job aggravating existing diseases and defects.
>
> Second, occupational diseases occur because they are actually produced by exposing workmen to concentrations of toxic substances beyond the threshold or toxic limit of those substances, or by the failure to provide and maintain the necessary equipment to protect the workers against harmful exposure.

FOUNDRY HAZARDS

The health hazards of an industry are determined by a physical survey of representative plants of that industry. Without going into the matter of the methods and standards used in conducting a survey of an industry, the results of that survey should evaluate the various health hazards existing. It should indicate the chief sources of the hazard, the extent and efficiency as well as the faults of equipment intended to protect workers. Wherever physical examinations are made, it is possible to correlate the physical findings with the data collected from the physical survey of the plants. Such studies indicate the foundry industry to have comparatively few health hazards. First might be mentioned the presence of dust of a mixed character. It is true that the harmfulness of a dust varies considerably, depending upon its chemical composition, its concentration, in some instances the par-

ticle size measurements of the dust, the length of exposure, and, perhaps, individual susceptibility.

Foundry dusts, however, do contain some substances which are of a hazardous nature. The majority of the dusts collected in foundries contain varying percentages of free silica, which is responsible for the disease known as "silicosis." The inhalation of silica dust produces a fibrosis, from which very few individuals die, but, unfortunately, silica dust in some way or other provides a fertile soil for the development of the tubercle bacillus and a large percentage of silicotics—some quotations are that about 75 per cent—die of tuberculosis.

In studies of the foundry industry, made by the Metropolitan Life Insurance Co., about 50 per cent of the dust counts collected exceeded 10,000,000 particles per cubic foot of air. About 10 per cent of those counts exceeded 100,000,000 particles per cubic foot. It was found that the chief sources of this dust are due to lack of maintenance of equipment. The foundry industry has the facilities for controlling the dust but, unfortunately, this equipment is not maintained at all times.

Dust Sources

There happens to be only three chief sources of dust in the industry, namely, sand conditioning, shake-out operations, and cleaning operations. Facilities are available for controlling the dust in all of these operations.

While the subject of dust is being discussed, there is another substance which is found in foundries where brass is founded; namely, lead. In these foundries, there frequently are sufficient amounts of lead dust to create a hazard of lead poisoning.

Temperature Changes

Foundrymen are frequently subjected to varying temperature conditions, to radiated heat and drafts. The author believes that the high rate of respiratory diseases is due more to the changing temperature conditions than to the dust hazard. He has never been convinced that the foundries have a serious silicosis hazard. While the company with which the author is connected did examine a number of men who had worked a long number of years in the foundry industry and found a certain amount of

fibrosis, no advanced cases of silicosis were found. Apparently, the disease progresses slowly among the foundrymen, so that the author feels that with the utilization of the facilities that are already in use in the majority of the foundries—and most important, is the maintenance of the equipment—the dust hazard can be controlled with very little trouble.

Other hazards are of a minor nature. In some instances, there may be an escape of gases around furnaces. These gases may contain carbon monoxide, hydrocyanic acid, sulphur dioxide and a few other gases which are, of course, in moderate concentrations very poisonous; but these are only occasionally found around furnaces due to leakage. Of the indirect health hazards, perhaps the chief is illumination. It was found in the studies to which the author has referred, that the illumination as a rule was poor.

MOST IMPORTANT HAZARDS

Of all the hazards, perhaps the two most important of the industry are dust—and the author feels that the dust hazard perhaps is more of a legal hazard than a health hazard, and, therefore, very important to control; and second, the varying temperatures, exposure to radiant heat and drafts.

CONTROL PROGRAMS

A control program should consist of two phases, the medical and the engineering. The medical phase of the program consists of initial or pre-employment physical examinations and periodical examinations. Unfortunately, only the larger foundries can afford the expense of maintaining their own medical departments. Likewise, an engineering department is generally impracticable for the average foundry. Therefore, it seems that the best plan to consider is a central organization equipped to make the necessary physical examinations and an organization with the personnel capable of conducting physical surveys at the plant. The author has in mind the set-up in Milwaukee, where a central organization provides a physician who interprets all x-ray plates and an engineer who conducts all surveys of the foundries.

Unfortunately, the average physician is not prepared to make the type of examination and interpretation required to diagnose every disease among workers in the foundry industry. The physical examination must include a very careful job analysis, particularly a history of the past occupation. Most important in the

physical examination of applicants who are exposed to dust conditions, is the x-ray examination of the chest. Unfortunately, there are few physicians who have had the experience necessary to properly interpret the findings of the average industrial worker.

There is another advantage in having a central clearing house, in that a uniform method of conducting examinations and a means of comparing the various x-ray findings is available. A central organization likewise is best in conducting a physical survey. Here, again, it is unfortunate that there are not enough engineers trained in this particular type of analysis.

With such a program, which strikes at the two chief causes of occupational disease, the author is convinced that the health hazards of the industry can be controlled and that foundry work will eventually become a safe employment for workmen.

(*Discussion of this paper begins on page 180*)

Industrial Health Hazards and Employer Responsibility

BY DONALD E. CUMMINGS,* SARANAC LAKE, N. Y.

Abstract

Dust has been in existence since man first walked the earth, according to the author, but it was not until the invention of the machine that dust became an industrial hazard. In this paper, the author discusses the action of dust in the lungs and points out that all dusts are not dangerous. Silica dust is one of the dangerous dusts but only when present in certain concentrations of certain particle sizes. The point that complicates the silicosis problem is the fact that in many cases there is also decided evidence of the presence of tuberculosis. He points out that in foundries many men with normal lungs work for years and do not contract silicosis although there may be evidence of fibrosis. The author explains the action of the dust particles inhaled on previous pulmonary injuries and states that workmen who are disabled by occupational fibrosis contracted in the foundry generally are those who exhibit evidence of concurrent pulmonary infection or injury. With regard to the executive's responsibility, he should inform himself on dust hazards, should conduct surveys of his plant and should inaugurate a program of control. In the latter section of the paper, the author groups employes and prospective employes into three general groups and explains which groups are good or fair risks and which should not be employed. He concludes with the recommendation that an educational program, similar to that used in "Safety First" campaigns, be inaugurated to combat the dust hazard.

1. Centuries ago, when man was just emerging as the dominant figure in the welter of life about him, we can visualize a thick-set figure clothed in animal skins setting forth from his cave in the early morning. He carried a rounded stone in his hand as he passed along a trail in search of food, and relied largely upon his keen senses to warn him of approaching game or danger. He inhaled deeply of the air brought to him by the fresh morning breeze, and suddenly tensed as he became aware of the approach of a hare. As the animal fled before him, he hurled the stone but misjudged the distance, and missed his prey.

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* Field Director, Saranac Laboratory.

NOTE: This paper was presented at a session on Industrial Health Hazards and Employer Responsibility at the 1935 Convention of A.F.A. in Toronto, Canada

2. In searching for his weapon, he discovered that it had struck a rock and splintered into sharp angular pieces which attracted his attention as useful objects. Later that afternoon, his appetite satisfied, this early man experimented with stone chipping in an effort to produce more perfect weapons or tools. During the process of fashioning a flint spear-head, the early artisan must have inhaled a certain amount of fine flint dust, but there is little to lead us to believe that his health or welfare was seriously affected thereby.

DUST IN ATMOSPHERE.

3. Before the first tool or machine was devised, the lungs of this early man had already accumulated considerable dust from the apparently clear air about his home. The elementary forces and the activities of living things were constantly producing dusts which were added to the atmosphere in varying quantities. Concurrently, these same forces were operating to rid the air of part of the contamination. Since none of the forces tending to eliminate the dust were perfectly efficient, particulate matter constituted a normal component of the atmosphere enveloping the earth and, because man exercised little or no control over the forces producing dust, he inhaled a portion of it with the first breath of life and continued to do so throughout his existence.

4. Not all of the dust which he inhaled was retained, for a considerable quantity was filtered out and expelled by the air-conditioning apparatus of his upper respiratory tract, which was provided with hairs, moist mucous surfaces, a whipping sea of cilia and the mechanism of cough. Moreover, a further portion of dust was returned to the atmosphere in the exhaled air, but a certain proportion entered the ultimate air sacs of the lungs and was retained there to be disposed of by the interesting processes provided by the pulmonary anatomy.

BEHAVIOR OF DUST IN THE LUNG

5. If we could have observed the living tissues of this early man under high magnification, we would have noted that wandering cells or phagocytes moved out from the walls of the air sacs and engulfed the particles which had entered the lung, thereby furnishing the dusts a possible means of transportation and more intimate contact with the body fluids but at the same time protecting the pulmonary structures from purely mechanical irritation. Some of the dust containing cells might have appeared to be greatly

stimulated by their ingested particles and would have migrated toward the nearest portal of entry, into the drainage system or lymphatics. Some of these stimulated cells would have come to rest at small catch-basins along the drainage system, but the greater portion of them would eventually have lodged in the cesspools or lymph nodes near the root of the lung.

6. At these points, there would have been a sufficient concentration of particles to pigment the structures so that the color of the dust could have been discerned with the unaided eye, had the lymph node been exposed to view. Other dust containing cells would have appeared quite differently than those just described, however, for they would have displayed little or no stimulation and would have remained in the air sacs lethargically taking in a new particle from time to time but failing to show any evidence of concern over their burden.

PARTICLE SIZE

7. If the lung of this early man could have been examined with all the microscopic, petrographic, and chemical skill of the present day, many interesting facts about the dust that they contained, would have been disclosed. This dust would have been discovered to have a well defined size distribution with none of the particles larger than 10/25,000-in. (0.0004 in.) in diameter, while 70 per cent of it would have been less than 1 to 2/25,000-in. (0.00004 to 0.00008 in.) in diameter.

TYPES OF DUSTS

8. The particles would have shown a great variety of constituents, some of them being derived from living things, or organic, while others would have been earthy, or inorganic in nature. Part of the organic dust would have been shown to be living bacteria highly stimulating and capable of causing the death of their host cells, while other parts of the organic material would have been composed of animal or vegetable cells. The inorganic components would have consisted largely of small particles of various rocks.

9. Certain of the dusts would have been readily soluble in the body fluids, and would have dissolved in the containing cells, forming either poisonous or innocuous products which in turn either stimulated and killed the host cells or left them unaffected. Other dusts would have been relatively insoluable and would have

remained in the pulmonary framework throughout the life of the tissues containing them. Some of these latter particles would have appeared totally inert, while others would have stimulated the phagocytes and created further change in the tissue.

MACHINERY INTRODUCED

10. Our early man was quite unconcerned about all these interesting phenomena and probably continued to chip flint objects for his tribe until he reached a ripe old age. With the passage of time, better tools were fashioned and a third great force for the production or elimination of dust was introduced in the form of machines.

11. The social group was organized to perform industrial activities and craftsmen appeared who devoted all of their working hours to specific skilled occupations. Frequently, these occupations involved the production of dust and the concentration in the atmosphere about the craftsman was often much greater than that which the artisan of the stone age created, because this modern workman was aided by more efficient tools. It was significant also that the craftsman continued steadily at his work, whereas the early artisan exercised his skill only as his fancy dictated in the hours not consumed by the struggle for the necessities of existence.

12. Certain of these craftsmen soon were observed to have an excessive mortality from one cause or another, and occupational diseases were recognized. About 400 years ago, Georgius Agricola in his famous "De Re Metallica" wrote as follows:

> "When the dust is corrosive, it ulcerates the lungs and produces consumption, hence it is that in the Carpathian Mountains there are women who have married seven husbands, all of whom this dreadful disease has brought to an early grave."

Later, Ramazinni, who wrote the first text-book of industrial medicine, attributed the high mortality from consumption among miners and stone workers to the sharp cutting action of the small bits of stone which these workmen inhaled. Other observers described the unusual appearance of the lungs of men who had worked in dusty trades of various kinds and Zenker coined the work *pneumonoconiosis* to describe the pulmonary changes which follow the prolonged inhalation of any dust or mixture of dusts.

13. Recent investigators have pointed out that excessive exposure to silica appears to constitute the greatest of all industrial

dust health hazards, and the term "silicosis" has been adopted to designate the specific condition which men develop after long exposure to this dust.

Effect of Silica Dust

14. In the normal individual, the reaction to inhaled crystalline silica is characterized by the development of a peculiar type of fibrosis or scar which appears in those areas where silica is deposited within the pulmonary structures. Silica-containing air enters the lung in turbulent motion and the dust is deposited uniformly throughout the entire organ. Since these particles are capable of stimulating phagocytes, they are rapidly transported into the drainage system or lymphatics, and the first detectable evidence of characteristic fibrosis appears in the lymph nodes situated at the root of the lung. Later, this reaction will manifest itself throughout the entire lymphatic system which encircles the blood vessels and bronchi.

15. As the reaction throughout the lymphatics proceeds, the effectiveness of this drainage mechanism is interfered with and the dust entering the lung is eventually unable to reach the lymphatics, and is thereafter deposited by the phagocytes in selected areas throughout the lung substance itself. Small, discreet, and uniformly distributed fibrous nodules from 2 to 6 mm. in diameter may eventually develop in large numbers within the lung, presenting in this stage the characteristic picture of advanced silicosis.

X-Ray Shows Changes

16. An excellent x-ray film of the normal individual's chest represents a projection of the pulmonary structure cast as shadows of varying density. Prominent among these densities, are those cast by the blood vessels, which compose the so-called vascular tree. The fibrous changes initiated by pure silica can be detected in the early stages on a good roentgenogram, by the increased densities shown at the root of the lung where the lymph nodes are situated. Further changes throughout the lymphatic system will become evident by an increased prominence of the vascular shadows caused by fibrosis developing in the lymphatics surrounding these structures. Finally the roentgenogram will reveal, as small round densities, the uniformly-distributed, discreet, fibrous nodules present throughout the lung in advanced silicosis, giving the characteristic "snowstorm" appearance described by roentgenologists.

Action of Inert Dusts

17. Inert dusts such as coal, hematite, gypsum, alumina, and limestone, produce no stimulation of the phagocytes and hence tend to remain within these cells for long periods without promoting any further action. When mixtures of silica and these inert dusts are inhaled together, the reaction so characteristic of silica is modified by the inert material which tends to slow down the changes which would result if the silica were present alone. These modified reactions are apparent not only to the pathologist, but also to the roentgenologist, and constitute the great bulk of all cases of occupational fibrosis. Experience has demonstrated that individuals with modified silicosis do not suffer from the excessive mortality which characterizes those groups with true silicosis.

Tuberculosis

18. If tubercle bacilli are inhaled, they are handled in much the same manner as dusts. Once in contact with the tissues, however, they are either killed and disposed of or they set up localized foci of infection. The organisms are transported by phagocytes into the lymphatics and the tissues then attempt to wall off these foci of infection by laying down an ever thickening mantle of fibrosis. This reaction is much the same as that which follows the inhalation of silica, except that it is generally localized to one or more portions of the lung and may be visualized and interpreted as tuberculosis with remarkable accuracy in a good x-ray of the chest.

Action of Silica on Tuberculous Lesions

19. Obviously, the lung which has been injured by a pulmonary infection, such as tuberculosis, is far less competent to deal with a dust, such as silica, than is the normal lung. Moreover, it has been proved both clinically and experimentally that the inhalation of pure crystalline silica tends to re-activate a pulmonary tuberculous lesion which would otherwise heal, and frequently renders such infection progressive and fatal. Even if the tuberculous lesion has successfully healed prior to the time when silica is inhaled, a far greater reaction to the dust occurs about the site of the old tuberculous scar than occurs in normal tissue, since the drainage system in that area has already been damaged and since the two proccesses apparently stimulate the tissues to produce an excessive amount of fibrosis.

20. Recent investigations have disclosed that individuals who have simple silicosis, uncomplicated with tuberculosis, are not generally disabled, even though their condition may be quite advanced. A careful physical examination frequently fails to reveal anything abnormal about such individuals, and the changes which have occurred in their lungs can be detected only by the x-ray.

PREVIOUS PULMONARY INJURIES

21. Silicotic workmen who complain of shortness of breath, chest pain, cough, or other disabling symptoms are generally found to have either a complicating pulmonary infection, usually tuberculous in nature, or some evidence of a previous pulmonary injury which has left a localized scar. These cases can be discerned on an x-ray film by the characteristic appearance of silicosis to which has been added the densities cast by the localized masses of pulmonary fibrosis which exist about the sites of the infection or previous pulmonary injury. Frequently, such cases fail to show tubercle bacilli in the sputum until shortly before death. In many instances, the disease is unusually chronic and only slowly progressive, manifesting itself largely by a progressive shortness of breath. Cases of this type are the prominent feature among the men actually disabled by a modified silicosis hazard.

22. Widespread misconception of the disabling effects of uncomplicated silicosis has arisen from the studies of early investigators who were unable to distinguish cases of silicosis from those complicated with pulmonary tuberculosis or other infections with the equipment or knowledge then available. These earlier investigations revealed silicotics who displayed shortness of breath, chest pain, cough, and other disabling symptoms which were ascribed to silicosis alone, since tubercle bacilli could not be found in the sputum. It should be realized, at the present time, however, that silicosis assumes a serious position as an occupational hazard largely because of its effect on pulmonary infections, predominately tuberculous in character.

DUST HAZARDS IN THE FOUNDRY

23. Though the foundry must always be considered as a dusty industry, the nature of its operations are such as to induce, for the most part, only a modified silicosis. Both mortality studies and clinical examinations of foundry workers fail to disclose the type of hazard associated with a pure silica exposure. Many men

in advanced age groups who have spent their entire working lives in the foundry industry are still capable workmen, suffering from no occupational disability, although most of them will be found to have some degree of pulmonary fibrosis. The workmen who are disabled by an occupational fibrosis contracted in the foundry are generally those who exhibit evidence of concurrent pulmonary infection or other injury. It must be recognized, in spite of these alleviating circumstances, that a certain occupational hazard does exist in all foundries.

THRESHOLD DUST CONCENTRATIONS

24. Any working atmosphere which contains more than a certain threshold concentration of silica will induce the formation of pulmonary fibrosis in workmen exposed to it over long periods of time. Information gathered from field studies made in many parts of the world indicate that a normal man may work for many years in air containing pure crystalline silica dust without impairing his health, providing the concentration does not exceed 5,000,000 particles per cu. ft. of air as determined by the standard method used in the United States.

25. This concentration constitutes a special value for the health hazards created by silica which may be designated as the primary threshold. The value of this threshold will be increased for those industries in which the silica hazard is reduced by the presence of modifying factors. The development rate does not always appear to vary directly with the concentration but increases slowly with the elevation of the dust level up to a certain value where the acceleration becomes very marked.

26. Concentrations of 100,000,000 or more pure silica particles per cu. ft. of air appear to be extremely hazardous and constitute a second special value which may be designated as the secondary threshold. Concentrations of pure silica above this secondary threshold lead to the rapid development of silicosis and men working in these extra hazardous atmospheres have been known to acquire true silicosis in less than two years. Examples of this type can be found among men dry drilling tunnels in quartz rock or sandblasting without protective equipment. Demonstrable silicosis usually develops in workmen exposed to pure silica in concentrations between the primary and secondary thresholds in from 5 to 30 or more years depending up the individual's susceptibility and the degree of the exposure.

27. Experience has shown that diminishing a hazardous dust exposure results in extending the time required for silicosis to develop and that even when it does occur, there is generally little evidence of disability among the workmen who contract it, unless they have a complicating pulmonary infection or other injury. All of the preceding remarks with regard to dust concentration apply only to those individuals without pulmonary abnormalities. The presence of pulmonary infections or other pathological conditions generally alters the normal susceptibility of dust diseases.

28. It appears to be true that the individual with arrested tuberculosis might be subjected to a health hazard in an atmosphere containing less than 5,000,000 particles of pure quartz dust per cu. ft. of air; while he might suffer no ill effects from exposure to fairly high concentration of inert dusts, such as coal, alumina, limestone or hematite. Obviously, the values given cannot be used arbitrarily to measure the degree of any hazard or to form the basis for legislative codes of good practice but they serve as one of the aids in bringing a given dust hazard under control.

RESPONSIBILITY OF EXECUTIVES

29. What then are the responsibilities of the executives of those industries in which the dust hazard is suspected? In the author's opinion, the first duty imposed upon the operator requires that he secure a thorough knowledge of the nature of the disease itself.

30. Many executives whose interest should be deeply aroused by this subject, unfortunately, assume the attitude that silicosis is just another "racket" and delegate the duty of keeping the organization out of trouble to minor officials. The subordinate officers, having been impressed with the general attitude of the management, are frequently powerless to inaugurate a comprehensive program designed to cope with all of the existing circumstances and delay constructive action by refusing to recognize that their operations are in any way affected.

31. The futility of this procedure is evidenced by the fact that claims eventually arise which compel recognition of the disease and the adoption of a proper policy at a time when conditions are much less favorable for its successful application than would have existed at an earlier date.

32. Some managements apparently regard the silicosis ques-

tion as a purely legal matter and rely largely on such counsel for determination of policy. This procedure tends to distort the problem by illuminating it largely from a single aspect. Obviously, it is equally inadvisable for a management to depend entirely upon the judgment or suggestions offered by either the medical, engineering or production members of its staff.

Administrative Requirements

33. The most important requisite to good administration of silicosis problems lies rather in an informed management advised and directed by authoritative opinion representing the legal, medical, engineering and production divisions of the industry and assisted by consultation with some organization qualified by long experience with the problem, if necessary.

34. Having divested themselves of preformed conclusions concerning their particular situation, the second responsibility of employers consists in inaugurating a thorough survey of their plant to determine the existence, nature and extent of the dust hazard. A survey of this type may include the physical and x-ray examination of the employees, the taking of occupational records, the determination of the nature and concentration of the dust suspended in the working atmosphere, an analysis of the mortality records in the district, and if possible, post-mortem examinations of old employees dying from any cause.

35. The actual importance of silicosis as an industrial problem has been greatly over-emphasized for several reasons, chief among which has been the reluctance of administrative officers to investigate and reveal the existing facts in their operations. The mantle of secrecy which has shrouded existing conditions wherever many dust hazards are involved, has served to exaggerate their significance. Coupled with this lack of accurate and complete information, there has been, in the United States, an unwillingness to provide well-framed legislation to regulate the compensation of workmen affected by exposure to dust. This, in turn, has resulted in the filing of numerous claims in civil court which allege that a personal injury has been incurred through the negligence of the employer in permitting men to work in a hazardous atmosphere.

36. The enormous amount of money involved in these civil actions, together with the confusion created by the varied decisions handed down by judicial bodies attempting to deal with this com-

plex question, has given an altogether unwarranted notoriety and importance to this subject. Unfavorable experience with civil actions, has prompted the hasty passage of occupational disease legislation in some of the United States where the facts are still unrevealed, and there is every reason to expect that unreasonable decisions based upon poor medical testimony, misinformation concerning the dust hazard, and a general tendency to attribute all ills to industrial conditions, will tend to discredit these laws and thus further prolong the unusual prominence accorded silicosis.

37. Administrative officers must further recognize that the situation which has been created in the United States, is now of an emergency nature, and that there is neither a sufficient amount of reliable information, nor a large enough number of properly trained and informed authorities in many localities to deal with the silicosis problem. Under the press of emergency, many so-called silicosis experts have appeared over night and technical publications have been flooded with silicosis articles, few of which have added materially to the general understanding of the subject, but many of which have served to confuse and confound everyone interested in evaluating the actual issue.

38. As is true of nearly all diseases known to the science of medicine, certain phenomena associated with dust diseases are not understood or are imperfectly explained by medical authorities. A much more unfortunate difficulty arises out of the fact that many members of the medical profession, whose authority cannot be questioned in their particular field, are erroneously informed on this subject and offer opinions which are accepted as true, to the further bewilderment of all.

39. The same criticism may be offered against engineers, public health officials or attorneys, whose knowledge of silicosis has not arisen out of long and intimate first-hand experience. For this reason, it may be advisable to consider consultation with some organization competent to analyse the information available so that a proper policy may be determined.

ADVANTAGES OF SURVEY

40. If no hazard is discovered by a thorough survey, both the employer and the employee are protected by the information secured. On the other hand, if a hazard is detected, the original study serves as a guide to the future program of control which should be promptly initiated.

Control Program

41. A control program in a dusty industry whose hazard has been defined, will include the reduction of the dust concentration in the working atmosphere and the application of protective devices, the establishment of certain physical standards for new employees, the selective placement of old employees on the basis of their physical condition and the adoption of an educational program to properly inform all those vitally concerned with the effects of a dust hazard.

42. Thoroughly reliable methods of determining dust concentrations are available and engineers equipped to utilize these procedures can discover the sources and extent of the contamination and devise means of either reducing the hazard to within safe limits or applying adequate protective devices. A constant check of the dust concentration in the atmosphere should be maintained and records should be kept to show the condition of the working atmosphere, the nature of the protective equipment and the total duration of time each workman is required to spend in a hazardous occupation.

43. A pre-employment examination, including an occupational history and excellent stereoscopic chest roentgenograms, should be given to every new employee. In general these examinations will serve to classify men into three main groups composed of (1) those whose chests are apparently normal, (2) those who have an occupational fibrosis without any other pulmonary abnormality, and (3) those who have tuberculosis or other pulmonary abnormalities either with or without occupational fibrosis.

44. In considering the desirability of employing men whose chests are apparently normal, it should be borne in mind that young men, probably up to the age of thirty or thereabout, are not altogether perfect risks for employment in a hazardous dust since they are in an age period during which they may still contract tuberculosis.

Risks Classified

45. In the author's opinion, men who show evidence of simple occupational fibrosis and who are past the age of thirty, as most of them will be, are excellent risks since the author does not believe that uncomplicated silicosis is ordinarily dis-

abling and since these men are past the age period during which they are likely to develop tuberculosis. These men may show some progression of their fibrosis after employment in a dusty industry but they will not tend to develop disability if they have been rigidly examined to exclude those showing any x-ray evidence of tuberculosis or other pulmonary injuries.

46. If this class of persons is to be discriminated against, it will create a most unfortunate social problem, since many skilled craftsmen perfectly capable of a lifetime of useful activity will be thrown out of work to become embittered and the prey of unscrupulous lawyers and doctors who will further complicate the situation by making the workmen claimants and neurotics. It is the author's belief that these men should not be eligible for compensation but if they are made so under the law, then legislation should also be provided to permit them to waive their right to compensation for an occupational disease, so that they may have the privilege which should be accorded to all free men—that of working at the task for which they are best suited. Providing this group is carefully selected to exclude infection and remains under medical supervision while in the dusty industry, their experience should be as favorable as any that the employer could choose.

47. As to the third group of men, an injustice is done to both the employer and the prospective employee by placing any person at work in a hazardous dust who has tuberculosis or other significant pulmonary abnormalities whether or not occupational fibrosis is present.

PLACEMENT OF MEN

48. In the presence of a known dust hazard, old employees should be placed, as far as possible, in those occupations most compatible with their health and welfare on the basis of the physical examinations which they have undergone. Men with normal chests who are past the age of thirty, or those with uncomplicated occupational fibrosis may be employed at any occupation, while young men under thirty should not be exposed to the operations which produce the most harmful dust and should be re-examined fairly frequently.

49. Those cases of inactive tuberculosis, either with or with-

out occupational fibrosis, should be carefully evaluated and every effort made to provide working conditions such that their health will not be impaired or their ability to earn a living wage interfered with. Men in this group should also be re-examined at frequent intervals.

50. Cases of active tuberculosis should not be employed in a dangerous dust either for their own safety or that of their fellow workmen, and should be encouraged to enter a sanatorium or to place themselves under the care of a competent physician.

Educational Plan

51. The occupational disease problem is now much the same as that presented by industrial accidents when the first compensation act was passed. Disabling conditions created or aggravated by exposure to harmful dust can be prevented or controlled but the final success of any plan designed to accomplish these purposes, will depend upon maintaining a broad educational program similar to that adopted in the "Safety First" movement. These policies are not only humanitarian but they are practical, and have been placed in operation in many hazardous industries employing thousands of men. The author sincerely recommends them for consideration.

(Discussion of this paper begins on page 180)

HEALTH HAZARDS AND EMPLOYER RESPONSIBILITY

DISCUSSION

D. M. Avey, President of A.F.A. and Editor of The Foundry, Cleveland, acted as chairman of the meeting at which the papers of Dr. McConnell and Mr. Cummings were presented.

PRESIDENT AVEY: In starting the discussion of these papers by Dr. McConnell and Mr. Cummings, I think the fact that we are meeting on Canadian soil is singularly fortunate, because we have available in Canada considerable experience which will be exceedingly valuable, I feel sure, to those foundrymen from the states. I would like to ask Dr. McGhie, Deputy Minister of Health for the Province of Ontario, to lead the discussion.

DR. MCGHIE: On behalf of the Department of Health of the Province of Ontario, I wish to express our appreciation at being invited, as officers of that Department, to listen and take part in the deliberations of your Association.

The Department of Health of the Province of Ontario is charged not only with the provision of adequate treatment for those who are sick but, what to me seems a far more important task, the prevention of illness. As a result, one of the most important divisions of the Department of Health is the Division of Industrial Hygiene, and closely associated with that is our Division of Tuberculosis Prevention.

I am particularly interested myself in this Division of Industrial Hygiene because, to me, it seems to be one entirely of research. Our experts in that Department, headed by the Director, Dr. Cunningham, do not claim to have the last word to give to you on the solving of your problems, but they are anxious to sit in with you to find out what the problems are and to study them as they appear in the various plants. The officers in that work tell me that the readiness with which the managers and directors of the various industrial organizations place at their disposal the facilities for studying the problem in the plant, facilitates the solving of these problems to a very large extent.

Our organization here, working as it does with the Compensation Board, I think comes close to the ideal, and those members of the staff who are here are far better able to explain its ramifications to you than I am.

DR. J. G. CUNNINGHAM[1]: Dr. McConnell and Mr. Cummings have given addresses which, to me, are exceedingly interesting. They are full of material which is very valuable and, really, I believe, leave very little to be discussed as far as the work of our Department is concerned. We are interested, of course, as a section of the Department of Health, primarily in the control of silicosis and other occupational diseases.

In the foundry industry, there is silicosis. Molders, for instance, as far as our experience is concerned, average for the development of silicosis nearly 30 years, which is a long exposure and compares very favorably

[1] Director, Division of Industrial Hygiene, Dept. of Health, Ontario, Canada.

with 10, 11 or 12 years' exposure necessary to produce the disease in certain occupational groups, and even shorter times in certain other small groups with heavy exposures. I think this should be recognized.

In certain other occupations in foundries, the occupational exposure is shorter but still around 20 years. However, on the other side, certain cleaning operations, particularly sand blasting, without adequate protection, result in the very rapid development of silicosis.

We recognize these conditions and undertake to deal with them as they exist. It is perfectly possible to do this and without any great disruption in the industry, either from the expense necessary for the use of special equipment or on account of legal complications arising out of claims. The very fact that it takes molders and grinders and some of the others a good many years to develop the disease suggests that even a moderate reduction in the amount of dust exposure would cause the disease to develop only after so many years that it would not be a practical problem. We, however, feel that dust production in foundries should be reduced wherever it is possible to do it. Admittedly, it is difficult to carry on foundry operations with no dust production, but if we can make a substantial reduction in the ordinary processes I am sure that this would have a real influence on the disease produced as a result of these longer exposures. The dangerous short exposures, such as occur in connection with sandblasting, demand a specific program for dealing with the dust.

Now, a word with reference to tuberculosis. As has already been indicated, tuberculosis is the main problem in relation to dust inhalation. It has been stated that silicosis on its own account, except in certain exposures—and they are few—would not be the serious problem were it not for the development of tuberculosis. It should be recognized first of all that tuberculosis occurs in foundry workers the same as in every other section of the community, quite apart from dust exposure, and, indeed, that fact is recognized in workmen's compensation legislation in Ontario.

On the other hand, there is an impression abroad that silicotics with tuberculosis do not spread the disease in the way that ordinary individuals without silicosis and with tuberculosis spread it. Studies, even locally, do not support that idea and, when we come to the control of tuberculosis, which has already been indicated as the main problem, we must recognize the value of physical examination. It becomes so much more important when one realizes that individuals exposed to silica are more susceptible to tuberculosis, so that one man with tuberculosis in the plant, whether it arises partly as a result of dust inhalation or not, is a menace to all the rest of those exposed to dust in that plant. Therefore, one of the main functions of the physical examination to which reference has already been made, is to see that that individual is not allowed to continue under those conditions.

Physical examination gives us information with which to start a man on employment; it assists us to control the tuberculosis problem as these men are examined from time to time; and finally it enables us to arrive at some sort of rational method of handling or dealing with the individual who perhaps has silicosis but has not tuberculosis, such as

would be spread from one to another, because, as Mr. Cummings says, it does seem to us very important that a reasonable disposition should be made of those individuals who are found to be affected but who are still able to do their work.

G. W. CANNON[2]: I have listened with keen interest to these able papers and the discussion, for as a foundryman, I am intensely interested in the rapid engineering advance being accomplished in the problem of dust control and disposal. I have been in the foundry industry all my life and in the years gone by we never heard of any foundry workers dying from the effects of dust. They did not seem to die from any cause, —they just dried up and blew away,—we were a pretty healthy bunch of mechanics as a class.

The modern production methods now used in our industry have, however, changed the conditions under which our employees must labor. Speed in production has brought about a concentration of effort in such operations as pressure blasting, whether it be pneumatic propulsion or mechanical projection. Speed at the shakeout has also greatly increased the generation of dust, heat and noise and it is in this hot, dust-laden atmosphere of these and other similar operations that it is necessary our workmen perform their labor; a condition which did not maintain in foundry practice in the years preceding the introduction of continuous and high speed equipment.

The problem of dust control and disposal is one in which we (I am speaking as a member of a firm employing 2,000 men) feel is a tremendous responsibility and one which cannot be thrust aside with indifference. In fact and to the contrary, we feel it must be met and conquered as soon as possible and that, with the aid of the best knowledge that can be procured through scientific research carefully analyzed and engineered by technical men skilled in this particular line of endeavor.

It is my opinion, however, that the successful solution of the problem cannot be achieved by the individual foundry and I suggest that within our own Association there be fostered an organization of men trained in this highly technical subject who would be compensated properly for the time and attention that must be devoted to the effort necessary to bring about a dustless foundry plant; such a setup would pay big dividends. I appreciate, as must all of us engaged in the foundry business, that satisfactory results in conquering the existing dust conditions and associated evils which militate against healthful conditions in which to work will involve large expenditures of time and money. It is not improbable that the larger foundry organizations can undertake this work independently with success, but the smaller foundries also have the same conditions to correct. The large and small units of the industry are interlocked in competition and expensive equipment installation has its reflection in competition. Successful correction measures in one plant will be of benefit in another so I would urge that our Association get into action in an orderly way, through proper organization processes to assist us in creating the best possible working conditions for the employees of the foundry division of American and Canadian industry.

[2] Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

In our plant we are only at the beginning of a program of betterments and we have a long way to go. We are undertaking the correction of the greatest evils first. Suitable designs for our mold shakeouts and core knockouts, one of our worst dust and heat producing sources, are being considered and it will involve the rebuilding of the molding units to gain the desired results; the cost will doubtless be high but we will have to stand the pressure.

In the Cleaning Department, we are confronted with an equally serious problem, that of taking the operators out of the blasting rooms. This will require the building of special fully automatic machines to handle, not just one design of a cylinder block or head, but a large variety of sizes and shapes. In this particular department we have progressed to the stage of selecting the most desirable design. The disposal equipment handling the disintegrated abrasive from grinders and the dust from our few remaining tumbling mills is also being revamped. We feel keenly that our responsibility in the betterment of working conditions is by no means finished if we are successful in the elimination of the dust-health menace. We are constantly engaged in battling with a problem that goes hand-in-hand with it,—the education of the men to take care of their own health.

Years ago the majority of our employees were foreigners. They dressed well from a health standpoint at least, they fed well on good food from the old-fashioned dinner pail prepared by the old-fashioned wife who took good care of them. Today the young men in the foundry are high school boys. They are tenderfeet; not strong enough of body to withstand the abuses that the old-timers were used to. In this campaign, our director of personnel is posting a new placard each week, advising them how to dress and what to eat as the seasons change and in general how to care for themselves. The work of the personnel supervisor does not end with the posting of placards; he sees that the messages which they carry are read and absorbed. We have even gone so far as to provide woolen undershirts,—the good, old-fashioned, perspiration-absorbing kind that many of us here present wore and found comfortable in the years gone by.

Successful operation means that conditions must be bettered from every standpoint in order that we may give our employees better places in which to work. Better working conditions will induce a better and higher grade product,—better products create greater profit.

PRESIDENT AVEY: That discussion is very pertinent, and it is one of the purposes, of course, underlying this general assembly, that we have here tonight. The whole problem is too large for the individual, and it is a rather large one for the entire inudstry. These matters are going to have to have the best consideration and the best brains of the best leaders we have in the industry.

JAMES MURPHY[3]: We all know that dust is the principal cause of silicosis and long before I ever heard of the word "silicosis," I took measures for the elimination of the extreme amount of dust that was in the foundry that I was operating at that time. That was back in 1907.

[3] Hamilton, Ohio.

The workers themselves have a faculty for creating a lot of dust that good management could avoid. In the cleaning of castings, it is far easier for them to stick an air hose into the casting and blow the dust all over the place than it is to dig it out by some other means. To eliminate that dust, I adopted a method of cleaning castings by means of a water blast. Castings that had formerly taken six or seven days for two men to clean, we cleaned in 35 minutes by this water jet. This method can be used in a great many foundries for the elimination of dust, particularly on large castings. Certain parts of the foundry, such as the shakeout, of course, cannot be reached that way, but they can be reached through dust arresters.

I believe that the State of Wisconsin has recently adopted some regulations for the use of water sprays. The sprayer can be used to keep down dust in a very good way, being a much better method for spraying gangways and keeping them moist than by taking a pail and sprinkling water over them, which may make them too wet. The use of sprayers for gangways is getting to be quite common. The principal thing is to keep the foundry damp.

MEMBER: We were faced with the same dust problem. Our foundry is a brass foundry. We started by washing the whole foundry from the ceiling down to the floor, taking all the dust off the beams, making a general clean-up. We had had our cleaning room on one side of the foundry but not separated from it. We moved that and closed it and separated it entirely from the foundry, with a partition, with swinging doors between, and the doors are always closed when the room is not in actual use.

We do a little barrel sandblasting. To overcome a big dust trouble there, we built a room outside of our foundry so that the operator has to go through two doors to get into the sandblast room. The valves that control the air are on the inside, so that at no time is anybody in the sandblast room while it is in operation. Beside the exhaust fan on the sandblast, we put an exhaust fan on the room, so that any dust that comes from the sandblast—and it does come from all of them, no matter how good they are—is pulled out of the room, or at least a good portion of it is.

We have cement floors and we sweep our floors at least three times a week and we sprinkle them all down before they are swept. The one problem that we do not think we have solved satisfactorily is our shakeout, because we do not have a conveyor and the shakeout is done between the molders. We are seriously considering putting in a conveyor, not so much for protection, but from the fact that we believe we could bring our shakeout operations into one room and have two to three men only around that operation.

A. B. ROOT, JR.[4]: It may be that the members will be interested in our experience in Massachusetts. Reference has been made to the necessity of keeping in contact with your state legislature and I suggest that it might be perhaps equally as important to keep in touch with your Commissioners of Insurance.

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[4] Hunt-Spiller Mfg. Co., Boston.

A little over a year ago, the insurance companies through their rating bureau requested the Commissioner of Insurance in Massachusetts to approve an occupational assessment rate of $4.00 per hundred dollars of payroll, in addition to the manual rate for industrial accidents. That request was made without any contact with the foundries or with the foundry organization that was known to exist there and had it not been for the fact that our Insurance Commissioner was very well acquainted with one of the foundry executives, it might very easily have gone through. Fortunately, the Insurance Commissioner called one of us up and said, "Do you know anything about it and will you come over and see if you think this is a reasonable request on the part of the companies?" As a result of the negotiations which started from that beginning, the rate, instead of being $4.00, was made $2.00.

And bear in mind that the rating bureau, and, through them the insurance carriers, had no statistics from their experience on which to base any request for an increase in rate. They were doing it simply to provide a back-log on which to fall in case they had cases of silicosis to settle in the future.

As a result of that, our Association appointed a committee to confer with the rating bureau on what might be done, first to reduce that below the $2.00 rate and, if it could be done, on what basis it might be done. We suggested to the rating bureau a rating plan of credits by which the carrying out of certain dust prevention features would entitle the foundries to credits on that $2.00, and the plan which they submitted to us was the most terriffic thing you ever saw, such suggestions, for instance, as ventilating a portable sand cutter moving up and down the shop. They were the most impracticable suggestions, I believe, that were ever put out. I think there is where our danger lies, through the insurance companies requesting increases in rates through the Commissions.

I would like to ask a question as to how the foundry interests of the country can best coordinate their efforts for the protection of their own interest through preventing unusually heavy increases in rates. The insurance carriers are organized. How can the foundries organize so as to have some common basis on which to protect their business interests against unusually heavy or unnecessarily high rates?

Another question I would like to ask of our two guest speakers tonight relates to the question of analysis of these cases. I have understood that the method of analysis was to take a sample of the rafter dust, make the dust count from the air floated dust, and to make their analysis for the silica content from the rafter dust. I have understood that there is a great deal of difference between the silica content of such rafter dust and the dust collected from air-floated samples. Is there any basis or any agreement that the chemical analysis of the silica content should be taken of that same air-floated dust from which the count is made?

DR. MCCONNELL: The chief reason for using the rafter dust for analysis is because of the difficulty of collecting a sample in the impinger apparatus. One of the Westinghouse engineers has developed a method, I think of electrical precipitation, which is capable of collecting

a sample sufficiently large for a silica determination. On the other hand, while we have been considering using this method, I still believe that we should have, at least in addition, an analysis of the rafter dust, for the reason that the dust on the rafters has been accumulating for over a period of years and you get a fairly representative sample of dust that has been arising from the various processes over a long period of time.

In collecting a sample at any one time, it is quite possible that the silica content may be extremely low during that particular process or that particular location, whereas on another day, under similar conditions, the dust may contain a much higher percentage of free silica. Therefore, I feel that we still should determine the amount of silica in the rafter sample.

At this time, I wish to mention some of the general protective measures that foundries are using, enumerating them only in a general way. Some foundrymen are substituting less harmful substances for harmful substances. A good example of that is in parting compound. I was told that foundry workers are very temperamental and at first it was said that it would be impossible to get them to use a non-silica parting compound. I have had some foundrymen tell me that they had to disguise the non-silica parting compound to get the men to use it and, when they did not know that it was different, they found it very effective.

Another method is the isolation of processes where it is possible to do so. One example cited here this evening was that of removing the cleaning room to one end of the foundry and separating it by partitions and exhausting the room. Where the dust concentration is high, it is always possible to protect the men working in that particular location, but you also protect a large number of men in the general foundry.

Another method is that of hydraulic cleaning. We have taken a number of dust counts during this hydraulic cleaning process and have found the counts to be extremely low. Wherever it is possible to clean castings with water, I believe it is an excellent method of control.

Another method is, of course, that of local exhaust ventilation. Where it is possible and practicable, all processes should be exhausted.

Some foundries are using a combination of air and water for cleaning the foundry. I think the apparatus is called a ginny and it is very effective.

In some foundries, it is found practicable to do the shakeout operations at night. I think wherever it is possible and practicable to mount your castings on a moving platform to one section of the foundry that may be isolated and protect the men doing that particular operation, it is an excellent method; but where that is impracticable, I believe the shakeout operation can in many instances be done at night or at least at the end of the shift, thereby exposing many less men.

It is also possible under certain conditions to substitute steel shot for sand. Here again, however, a number of foundrymen believe it is impracticable. On the other hand, we must remember that there are different types of sand. Some sands fracture more easily than others and those sands are much more of a hazard than those which do not fracture easily. So that, with your isolation, your substitution, your local

exhaust,—and we must not forget general ventilation, but we must also be careful that the general ventilation does not interfere with the local exhaust systems,—your combination of water and air for cleaning purposes, and the removal of unnecessary equipment, or, in other words, good order in your foundries,—you have all these very valuable methods in reducing and controlling your dust hazard.

V. HYDAR[5]: I believe we have instituted at the Falk Corporation some things that will prove interesting for they have proved effective in removing or at least minimizing the dust hazard.

The spray which was referred to a while ago is a home-made gadget. We use a welding tip for the tip of the spray. Water is fed to this device by means of a little manifold body to which the welding tip is attached. It is discharged through the small holes around the periphery of the tip, and air from the air line through the center hole. This atomizes the water. Quite a spray can be shot up into the air to help bring down dust. Also it can be used for spraying castings that are in the process of chipping without getting them too wet. In those cases where the chilling effect of water on the casting would be detrimental, one can still dampen them without chilling them seriously.

Our silica wash problem, I feel, has been quite well met in that we have gotten away from the old idea of mixing the dry silica flour with molasses and water in order to produce our silica wash. We buy a prepared compound which is rather pasty in substance, put it into a mechanically operated agitator, add enough water to it to give it the proper consistency, and the men can draw it out of a tap at the bottom of the agitator as they need it.

Perhaps the most outstanding thing that we have done is putting dust arresters and exhausting equipment on our sand mixers. We have tried two different types of housing on our sand mixers, and both have been quite efficient and effective. One of them goes up vertically from the top edge of the sand mill and terminates in a very flat conical top which has an air exhaust fitted to it. The other goes up in about a 45 to 50 degree cone from the rim of the mixer and also is connected with an exhaust fan. The dry ingredients are fed to the mixer through batching hoppers which have double compartments, or, rather double traps to them. The first trap opens from the bins to a compartment which contains or can contain just so much of the ingredient; and then a trap opens from that compartment into the mixer. The housings are equipped with sliding doors that can be closed once the batching has been completed and mixing proceeds. But we have found, in testing them, that even with the doors open, there is a sufficient draft to keep all dust from getting out into the foundry.

We have gone through the usual cleaning up and painting up process. We have used a lot of white paint and aluminum paint, largely with the idea that dust will show up more readily on light colors, and in that way we know just where to concentrate our efforts in order to keep down the hazard. Our big problem is still shakeout control.

MR. CUMMINGS: I would like once more to re-emphasize the import-

[5] Falk Corp., Milwaukee, Wis.

ance of physical examinations in preventing the occurrence of occupational diseases. A young man who enters a dusty industry, with a small lesion of tuberculosis may develop a larger lesion in a relatively short time. He may develop disability or may die and in all probability it will be necessary to assume that the course of his disease has been unfavorably influenced by his occupation. On the other hand, one may find many men past fifty years of age who have worked in high concentration of dust in foundries or other industries throughout their lifetime and who are still capable workmen in spite of the large amounts of dust which they have inhaled, because they were properly qualified for their tasks from the onset of exposure to dust.

The significant thing for you to consider is the fact that you must select your employees in order not to offer them an unusual risk. No matter how safe your foundry appears, it may still have enough dust in it to injure the man whose chest has already been damaged by an infection. If you will carry that one thought away with you tonight, you will have carried more valuable information than all of the engineering suggestions that could possibly be offered for the control of occupational disease.

H. S. WASHBURN[6]: On this question of examination before employment, which, of course, I believe we all think is necessary, how frequent re-examinations should be made of employees in order to be effective? Mr. Cummings speaks of having a later examination.

MR. CUMMINGS: That is a difficult question to answer. Tuberculosis is a disease which may be contracted at any time. A man may be examined today and contract tuberculosis tomorrow and he may work in your employment during the time he is contracting it. There is an opinion that tuberculosis is usually contracted in the early age groups. I do not wish to imply that the disease manifests itself at early ages only. One may become ill with tuberculosis at 50 or 60 or any other age period, but present information indicates that if one does become ill at 50 or 60, the disease was probably present at 20 or 25. I believe that young men are more likely to contract tuberculosis than others and, for that reason, they should be examined rather frequently.

Men in your employ who have tuberculosis which may be arrested or which may not be active enough to justify their being removed from the industry should also be examined rather frequently.

The general conclusion is that where men of all age groups are employed and are working full time, they should be examined at least annually, and that specific cases may need examination more frequently. In any event, men should be examined at least once every two years to screen against those possible cases of tuberculosis which may have developed since the last examination. The physical examination is intended to discover tuberculosis rather than silicosis and experience in each plant or industry will soon dictate how frequently examinations must be made. If examinations are made annually and no new cases of tuberculosis are found, a decision may be reached to examine every other

[6] Plainville Casting Co., Plainville, Conn.

year, but in the end, examinations should be made often enough to pick up cases that may be developing particularly among the younger men who enter your employment.

MEMBER: In examination of these employees, on our first examination we find three or four cases of silicosis. What do we do with them?

MR. CUMMINGS: Dr. McConnell can probably answer that question better than I can, but we have both had experience with examining thousands of men. At the present time we are conducting a general survey of a rather large industry employing somewhere between five and six thousand men, all of whom have been examined, many of whom are silicotic, some of whom are tubercular. We try to do what I outlined in my paper. We separate these men into three main classes, those who have normal chests, those who have evidence of occupational fibrosis, and those men who have some evidence of tuberculosis. The men who are young and who have normal chests, we try to initiate into the industry by placing them in the less dusty positions where we still have them somewhat under observation. The men who have silicosis, obviously have it already, they are good workmen, and we do not discriminate against those men in any way. We let them continue at their work. We do everything we can to improve the conditions under which they are working, obviously.

Men who have tuberculosis are dealt with as individuals through the medical division in the industry. Each of those men is judged on his merits. If he has active tuberculosis, we would simply suggest that he must be immediately removed, and there is generally no question about that, because it is realized that he is endangering his own health and that of his fellow workmen.

A man who has inactive tuberculosis, which may be a small lesion or it may be rather an extensive one, is dealt with on the basis of his physical condition. If he is rather badly affected, we suggest a job such as a night watchman or some such thing as that. If his lesion is small and not regarded as active, he is given a place of selected employment.

There is not enough tuberculosis in any dusty industry that I have encountered to make it impossible to place a number of men that are found in that industry at selected jobs. It is rather surprising to find that with slight improvement in the conditions under which these men work, their subsequent examination inevitably, or almost inevitably, reveals improvement in their condition rather than retrogression.

We do not discriminate against silicotics,—I would like to make that point clear,—unless they are disabled, and we find in the most instances that such men have what we regard as some complicating condition.

MEMBER: Should an x-ray examination be made?

MR. CUMMINGS: We make the most careful x-ray examination that we are permitted to do. We use the best equipment. We think that is essential. We ask for competent interpretations. The diagnosis of silicosis or tuberculosis is in the realm of the medical expert and I think it will have to remain there for some time. The ordinary practitioner,

capable as he may be, is generally unfamiliar enough with this particular field to qualify, originally at least, for that work.

MEMBER: Are there any authentic published negative reproductions that would guide, not the amateur in x-ray but a physician who has pursued it beyond the experimental stage, in differentiating between silicosis and tuberculosis?

MR. CUMMINGS: Yes, I think there are. The question of differential diagnosis of silicosis is one that is difficult and though one might get reproductions of cases which were typical for any given industry, it would be quite possible to bring forth films which simulated the appearance of the films that were used for demonstration which might consist of quite another pathological process, and hence I would still suggest that this particular field be left in the realm of experts, much as Ontario has delegated its authority to people who have made a special study of it.

Dust Collection in the Foundry

By S. D. Moxley,* Birmingham, Ala.

Abstract

Due to the need for preventing health hazards in foundries and to the increasing inclusion of references to dust elimination in state labor and occupational disease acts, greater attention must be paid to dust collection in foundries. A most economical way to meet this problem is to do a good job of house cleaning and by the installation of proper equipment for eliminating dust. The dust collection problems consist of three phases, apprehension, collection and disposal. Each of these three phases are discussed. Types of equipment are shown and compared. Dust characteristics are described. Under collection seven types of equipment are listed and discussed. In conclusion, it is stated that it is for the engineer and foundryman to properly analyze the problem at hand and to ascertain the degree of fineness of dust it is expected to collect before choosing the collector.

1. In recent years there has been an increasing interest shown in the prevention of dust in the foundry. Many of the northern and eastern states have references to dust elimination in their labor laws and quite a number have included occupational diseases caused by excessive dust inhalation in their workmen's compensation laws. This legislative action is rapidly spreading to other states and will in time no doubt include all of the states in the Union. Industry is vitally interested in this problem from the standpoint of health, dust nuisance in plant and surrounding community, and depreciation in equipment.

2. Undoubtedly the most economical way to meet this problem is to do a good job of house cleaning first and then install the proper equipment for eliminating the dust. There are so many kinds of equipment and methods used in the various phases of dust collection and air conditioning that the engineer and foundryman faced with dust problems sometimes become confused while at-

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Note: This paper was presented at a session on Dust Control and Safety Codes at the 1935 Convention of A.F.A. in Toronto, Canada.

tempting their solution. There is a methodical approach to the problem in every case, and there are a few basic principles involved which, while familiar to most engineers, are not always practiced in the foundry. It is the aim of this paper to clarify some of the points that most commonly cause confusion and result in inefficient and inadequate systems.

3. Quite often a system is designed for sand conditioning as well as elimination of dust nuisance. The same equipment can perform both of these operations satisfactorily, as usually they are inter-related. It is not often in the foundry that the recovered material has any economic value, therefore the separation of sizes of particles collected is not important. The problem then naturally breaks down into the following three distinct phases: Apprehension, collection and disposal.

APPREHENSION

4. In most cases the apprehension of the dust is the simplest but least understood of the problems. Almost without exception the best place to catch the dust is at the point of creation, as once it is liberated into the atmosphere it is very difficult, if not impossible, to recover.

Use of Hoods.

5. It is common practice to provide hoods over dusty areas which are fitted with suction pipes leading to the collector. This is illustrated in a general way by A of Fig. 1. In this type of installation the hood should be as small as possible and the openings in the hood reduced to a minimum. It has been found by the writer that with most foundry dust it is necessary to maintain a velocity in all hood openings of from 250 to 300 ft. per min. to prevent dust escaping from the hood. Fig. 1 B illustrates roughly the use of a small hood attached to a flexible exhaust pipe, which has been used quite successfully in connection with snagging wheels for grinding castings. There are many other variations of this principle used in connection with grinding operations.

6. Fig. 1 C illustrates a close fitting hood applied where dry sand is fed on a belt. The hood openings are kept as small as possible.

7. When conditioning sand by removal of fines, it is most effective to pass all of the shake-out sand through a current of air. A successful method of removing the desired size of particles is

shown in Fig. 1 D. A constant velocity and volume is maintained in the duct at all times. The end of the duct is provided with a hinged hood having an opening near the sand stream, approximately 50 per cent larger than the duct itself. This hood can be adjusted to varying distances from the sand stream, which regulates the effective velocity through the sand stream and hence the particle size removed from the sand. As the air velocity in the

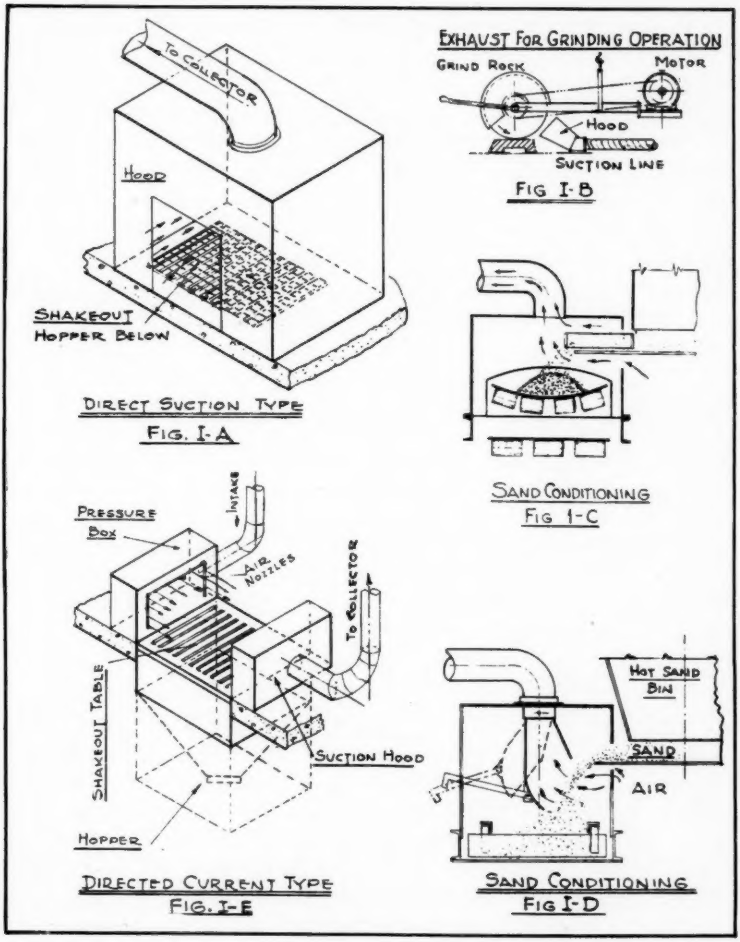

FIG. 1—TYPICAL DEVICES FOR TRAPPING DUST.

duct is always greater than at the opening of the hood, any particle which is picked up at the hood opening will surely be carried in suspension to the dust collector with no clogging of the air duct.

8. A method of controlling dust known as the air curtain dust control system has recently been developed and patented which has proved quite successful. Fig. 1 E illustrates its application to a shake-out station. A pressure box is provided with thin slots on the top and sides which keeps a thin layer of air moving at a high velocity over and around the shake-out operation. This prevents the dust generated in the shake-out operation from passing through the air curtain and into the atmosphere. At the other end of the station is a suction hood which receives the projected air curtain and exhausts it along with the dust laden air arising from the shake-out. The air is passed through equipment which removes the dust before it is re-circulated.

9. In sand conditioning machinery, where the sand is handled in many types of machines and conveyors, there are of necessity large amounts of dust created. It is usually possible, although sometimes inconvenient, to provide practically all such equipment with hoods which are exhausted to a dust collector. The removal of fines for sand conditioning purposes should be done at the shakeout while the sand is hot, as this is usually the first point of origin of dust in the plant. If separation is made at this point there would naturally be less dust to escape in the remaining operations. Oftentimes it is almost impossible to provide suitable hoods for shake-out and cleaning stations. In such cases these departments can be enclosed or moved to a distance from the other operations to prevent atmospheric contamination in the rest of the plant. The men in these departments may be provided with suitable respirators.

Correct Design of Hood Pipes.

10. Correct design of the pipes connecting the hoods to the dust collectors is essential to an efficient system. Branch lines should enter the main at the smallest possible angle and the main should be increased in size proportionately at each connection to prevent variation in the velocity of the air. These branch lines should enter the sides of the main. Dust pipes which incline downward in the direction of flow usually give trouble by clogging.

11. A system should contain as few elbows as possible and they should be of the longest radius permissible and never less than

$1\frac{1}{2}$ times the diameter as measured on the center line of the elbow. Ordinary foundry dust can be handled with little clogging of the pipes by an air velocity of between 2500 and 3000 ft. per min.

COLLECTION

Types of Collectors.

12. In dust collecting equipment for sand conditioning and dust nuisance prevention in the foundry, the following types of equipment usually are considered:

Centrifugal.
Centrifugal, (Fan Type).
Cloth Screen.
Cloth Bag.
Electrical Precipitation.
Washer.
Froth-Flotation.

13. Each of these types has distinct advantages in certain fields and the writer believes there is no particular type that can be economically and satisfactorily applied to all problems. It should be remembered that every dust prevention job is more or less peculiar in itself, and the equipment selection should be the one best adapted to all phases of the problem.

Dust Characteristics.

14. Fig. 2A shows certain characteristics of dust, and the general range of the various types of dust collecting apparatus with reference to recovery. This chart reproduced from the original supplied by the American Air Filter Co., Inc. has been modified slightly by the writer with reference to range of recovery of grain sizes by some of the equipment suggested for recovery. This has been done to make it more applicable to foundry dusts.

15. The dust to be recovered should be analyzed for the following:

(a) The nature of the dust from the standpoint of grain size and percentages of the various sizes of particles.

(b) Specific gravity.

(c) Amount of clay or other sticky substances contained.

(d) Moisture.

(e) Temperature.

(f) The degree of fineness it is necessary to collect (this factor is usually determined by the shop conditions and the proximity to the surrounding communities).

Hood Openings.

16. Next, the hoods at the various points of collection should be designed and the areas of hood openings determined. With known velocities the volumes of air can be determined and correct design of air ducts made. These calculations will also show the volume of air to be handled by the dust collector and the pressure under which the system is to operate.

17. If possible, the probable dust concentration per cubic foot of air which will be delivered to the dust collector should next be determined. Usually, all of this information can be determined by the local engineer in cooperation with testing laboratories or engineers representing manufacturers of dust collecting equip-

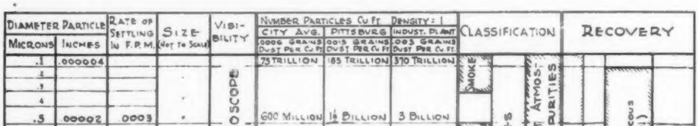

FIG. 2A—SIZE AND CHARACTERISTICS OF AIR BORNE SOLIDS (REPRODUCED BY PERMISSION OF THE AMERICAN AIR FILTER CO. SLIGHTLY MODIFIED BY S. D. MOXLEY WITH REFERENCE TO RANGE OF RECOVERY OF GRAIN SIZE AND THE EQUIPMENT SUGGESTED FOR RECOVERY.)

Table 1
Dust Collector Characteristics

Type	Style*	Vol. Air Per Sq. Ft. Cloth	Min. Grain Size Microns	Temperature Limits	Moisture Limits	Maximum Dust Concentration Inlet Grs. Cu. Ft.	Concentration Outlet 5 Gr. Inlet	Efficiency 5 Grs. Conc.	Relative Cost 15,000 Cu. Ft. Unit
Centrifugal Collectors	A	....	70–75	800° F	Dewpoint	Any	.75	85%	$ 750
	B	....	70–75	800° F	Dewpoint	Any	.75	85%	1,000
	C	....	50–60	850° F	Dewpoint	Any	.50	90%	2,000
	D	....	35–40	800° F	Dewpoint	Any	.25 to .10	95% to 98%	2,500
	E	....	35–40	1800° F	Dewpoint	Any	.25 to .10	95% to 98%	3,000
Centrifugal Fan Type	F	....	25–30	750° F	Dewpoint	150	.50	90%	2,000
Cloth Screen	G	2 Cu. Ft. 10 Gr. 3 Cu. Ft. 5 Gr.	5–10	200° F	20° Above Dewpoint	10	.05 to .025	99% to 99.5%	4,000
Cloth Bag	H	4 Cu. Ft. 10 Gr. 6-8 Cu. Ft. at 5 Gr.	5–10	Cotton 200° Wool 250° Fahr.	20° Above Dewpoint	20	.05 to .025	99% to 99.5%	6,000
Electrical Precipitation	I	....	Any Suspended Particle	None	None	Any	....	....	10,000
Washer	J	....	5–10	Boiling Point of Liquid	None	....	....	....	4,000
Oil Flotation	K	....	5–10	Boiling Point of Liquid	None	25	.017 and up	99.7%	4,500

*For detail sketches or illustrations of apparatus of these styles, see Figs. 1, 3, 4, 5, 6, 7 and 8.

ment. When these facts are obtained, the chart of Table 1 will assist in the selection of the proper equipment.

Dust Collector Characteristics.

18. Table 1 shows general characteristics of the various collectors when collecting dust, which the writer believes is fairly typical of that found in the foundry. The results shown are based on tests run on dusts arising from shakeouts and sand conditioning machineries in continuous molding operations and in jobbing foundry practice. All tests were run using a concentration of the collector inlet of approximately 5 grains per cubic foot. Figure 2B shows particle size distribution of new washed sharp sand, molding sand with clay added for a binder, and the dust removed from the molding sand for sand conditioning and dust nuisance prevention. Figure 2C shows a particle size distribution of the dust removed from the system to a larger scale and represents the average dust characteristics upon which the values in Table 1 are based. Figure 2D shows particle size distribution of average dust by numbers of particles instead of by weight as is shown in Figure 2C. This curve represents average characteristics of several tests where the sample was obtained by the impinger method and the particles were counted on light and dark fields under a magnification of 500. Particles under one micron in diameter were ignored. It will be noted that the atmospheric distribution curve bears a striking similarity to the curve representing the air exhausted from the bag-type dust collector. The values shown for volumes of air per square foot of cloth, minimum grain sizes, temperature and moisture limits and maximum dust concentrations represent what the writer believes to be within safe practice for satisfactory operation. Each will collect small portions much finer but will also allow certain quantities of much coarser material to escape. The temperature limits indicated assume that no form of heat exchanger is used in the system.

19. Outlet dust concentrations of collectors shown as styles A, B, E, F, G and H have been determined by the writer using the impinger method. The efficiencies were then calculated based on the above conditions. The values given in Table 1 for the remaining collectors were obtained from reported tests made elsewhere and from such information as was available. Installation costs are based on average conditions. Due to the wide variations in foundry

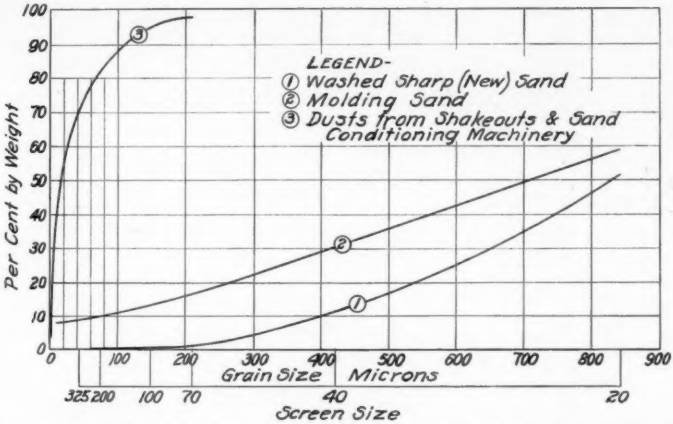

FIG. 2B—PARTICLE SIZE DISTRIBUTION OF NEW WASHED SHARP SAND, MOLDING SAND WITH CLAY ADDED AS A BINDER, AND DUST REMOVED FROM MOLDING SAND FOR SAND CONDITIONING AND DUST PREVENTION. PARTICLE SIZE DISTRIBUTION OBTAINED BY U. S. BUREAU OF STANDARDS PIPETTE METHOD.

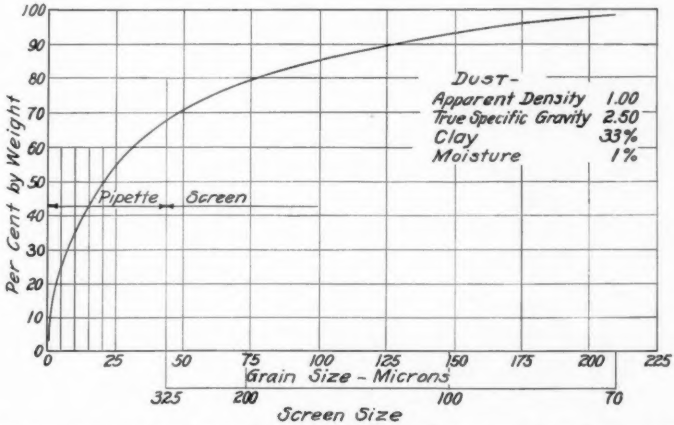

FIG. 2C—PARTICLE SIZE DISTRIBUTION OF THE DUST REMOVED FROM THE SYSTEM AT LARGER SCALE.

conditions all of these values should be used only for comparative purposes.

20. Examination of the characteristics of centrifugal collectors A and B of Table 1 will readily show that these styles are only suited to coarse material, and are not able to collect, with any high degree of efficiency, fine foundry dust. Their usual ap-

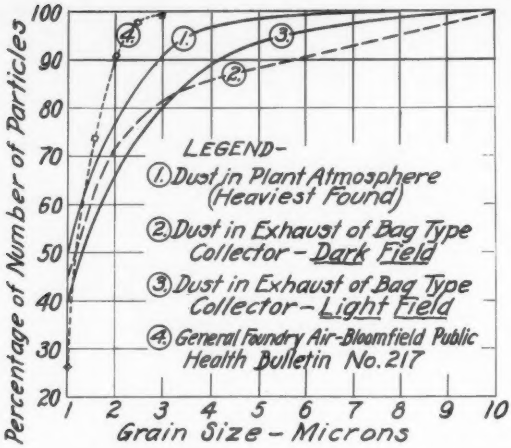

FIG. 2D—PARTICLE SIZE DISTRIBUTION OF AVERAGE DUST BY NUMBERS OF PARTICLES INSTEAD OF WEIGHT AS SHOWN IN FIG. 2C. SAMPLE TAKEN BY IMPINGER METHOD AND COUNT MADE USING MAGNIFICATION OF 500.

plication is in sand conditioning, exhausting tumbling barrels, etc., rather than preventing pollution of the atmosphere. These general types are familiar to foundrymen. (Fig. 3, A and B.)

21. Style C, Table 1, indicates reported characteristics of a centrifugal cone collector which consists of a number of small centrifugal cones connected as a unit. (Fig. 3 C.)

22. Styles D and E, Table 1 (Fig. 3, D and E), show the more efficient styles of centrifugal collectors. The double scroll type, shown as style E, is one of the most efficient of the centrifugal collectors from the standpoint of collection of the finer particles. The skimmer type collector is shown as style D (Fig. 3 D), which has a relatively high efficiency in collecting fine particles.

23. The characteristics of the fan type centrifugal collector are given as style F, Table 1. It is a combination fan and centrifugal collector driven by an electric motor. (Fig. 3 F.)

24. If the dust concentration is high, and the percentage of fine particles is high, with a relatively low specific gravity dust, these types of collectors can not be depended upon to solve a dust nuisance. When 50 per cent or more of a dust passes through a 325 mesh screen these types of collectors are apt to release into the atmosphere objectionable amounts of dust. This is particularly true when a large proportion of these fine particles is clay or other binding materials of impalpable character. However, on dusts

having high specific gravity such as pure silica sand, this type of machine can be efficient in the collection of extremely fine particles.

25. The cloth screen filter which has found wide application in the collection of foundry dust has characteristics shown under Style G, Table 1 (Fig. 4). Where it is necessary to collect the extreme fines, and where the dust concentration per cu. ft. of air is not high, this type of equipment has proved most efficient. The limitations of this apparatus are usually found in the amount of moisture in the air, the temperature, the nature of the dust, and the dust concentration of the air stream.

26. Where high concentrations are combined with relatively high percentage of very fine particles, and where the particles

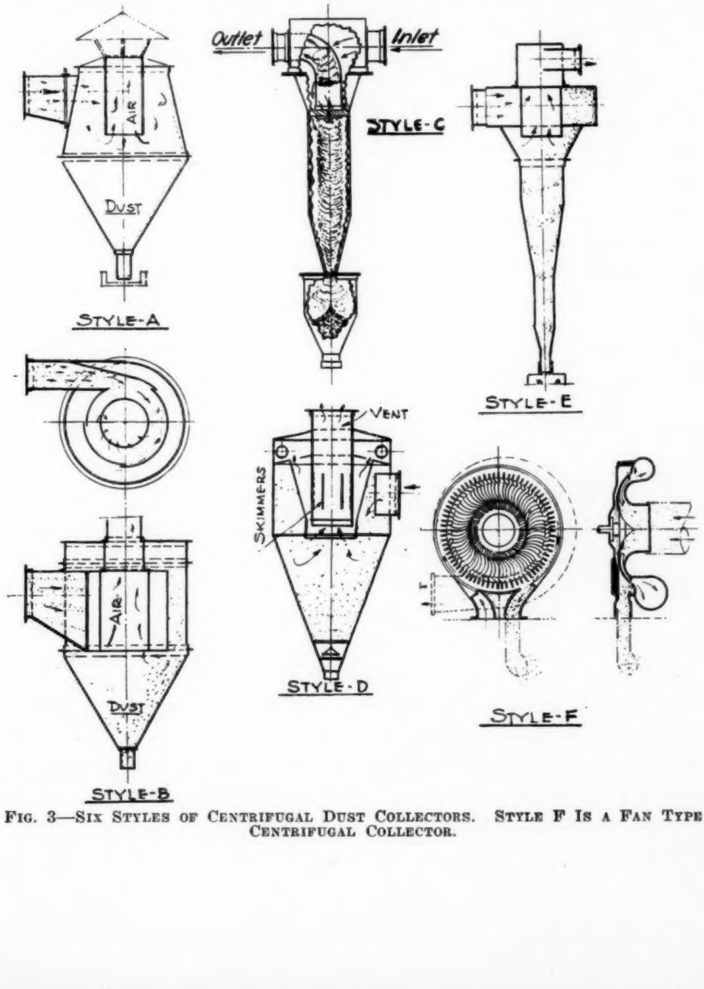

Fig. 3—Six Styles of Centrifugal Dust Collectors. Style F Is a Fan Type Centrifugal Collector.

themselves are composed of clay or other sticky substance with moisture included, the shaking mechanism is usually found inadequate to clean the cloth screen. This shaking is usually done by mechanically operated rappers, and the air must be cut off during the rapping operation. Practically any size material can be collected efficiently by this type of apparatus if it is provided with an expansion chamber or balloon type manifold which will first settle out of the air stream the larger particles.

CLOTH BAG COLLECTORS

27. For the higher concentrations of dust and the greater percentages of impalpable fines the bag type cloth filter of Style H, Table 1 and Fig. 5, has been found more satisfactory. It is also more effective on relatively high moisture conditions. The reason for this is that the bag type collector has a much more effective shaking mechanism. The collecting unit is divided into compartments, each containing from 15 to 18 bags suspended on a rack which is shaken by pneumatic equipment. During the shaking period the compartment is disconnected from the fan and the direction of the air is reversed. The compartment is then automatically cut into service while another compartment is disconnected for shaking. By this arrangement only a small part of the capacity of the collector is removed from service during the shaking operation. Large amounts of moisture can be handled by the bag type collector with little difficulty if the temperature of the air is kept some 20 degrees Fahr. above the dew point.

ELECTRICAL PRECIPITATION

28. Another type of dust collecting equipment which may require consideration in the collection of foundry dust is the electrical precipitator. Characteristics of this equipment are given in Table 1. The principle of operation is to pass the dust laden air through a strong electrostatic field where the dust particles are ionized. In this condition they will be attracted by the electrodes of opposite polarity.

29. A simple form of the apparatus is shown as Fig. 6, where a fine wire is suspended in and insulated from a vertically mounted pipe. By electric connection the pipe acts as the positive electrode and the wire as the negative electrode. Dust laden air passing through the pipes becomes a part of the electric circuit, and is ionized, caused the suspended particles to be precipitated on the

interior of the pipe. Another form of this apparatus is also indicated (Fig. 6) where vertically supported concrete slabs form the positive electrodes, while vertically suspended wires between these slabs form the negative electrodes. In this case the ionized dust particles are attracted to the sides of the concrete slabs. They are

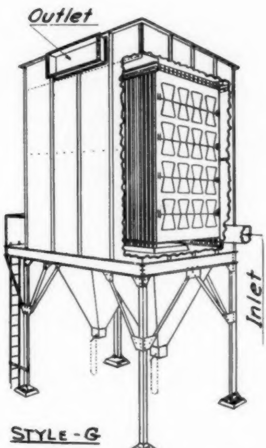

FIG. 4—CLOTH SCREEN FILTER.

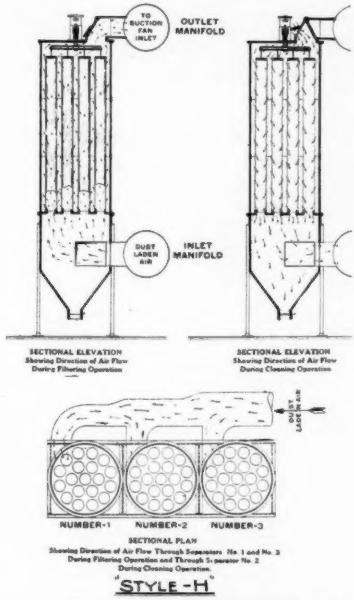

FIG. 5—BAG-TYPE CLOTH FILTER.

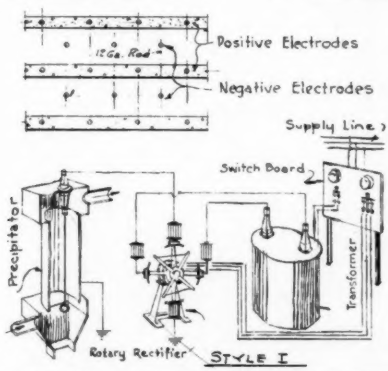

FIG. 6—TWO ELECTRICAL PRECIPITATION TYPE COLLECTORS.

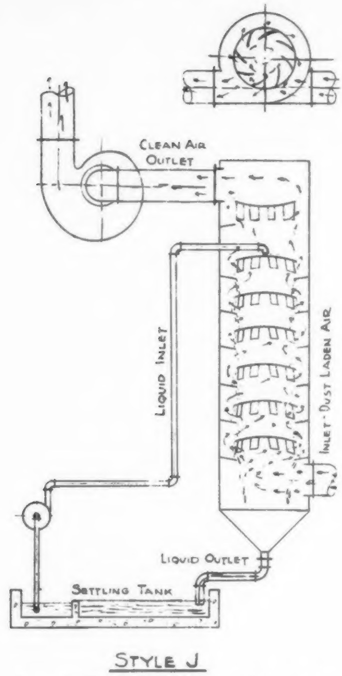

FIG. 7—WET DUST STYLE COLLECTOR.

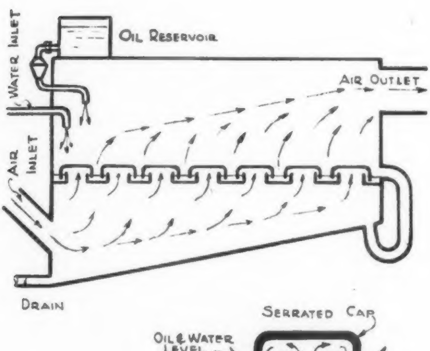

FIG. 8—FROTH-FLOTATION STYLE COLLECTOR.

discharged by gravity into hoppers below. Sometimes mechanical scraping or cleaning devices are used to remove the precipitated dust.

30. The efficiency of this type apparatus on fine particles can be very high if the equipment is designed properly. The writer does not know of an installation of this kind being used for the collection of foundry dust. The reason it has not been used in this field, probably, is the high initial cost of the equipment. With the rapid improvements now being made, this disadvantage may shortly be overcome.

31. Style J (Fig. 7) shows an adaptation of the wet dust collector principle which has recently been applied to the collection of foundry dust. The dust laden air is introduced at the bottom of the tower tangentially. Water or other absorbing liquid enters the top of the tower and falls in a spray through succeeding plates, making contact with the upward moving dust laden air. Vanes are mounted on the bottom of the center plates which cause the air to travel upward in a spiral course. There are two washes per plate and usually six plates or twelve washes are used.

32. The collected material is absorbed in the liquid and flows by gravity from the bottom of the tower into settling tanks. The water from these tanks is recirculated in the tower and the sediment is disposed of by the most convenient means.

33. In Table 1 there are given reported characteristics of a collector of this type (Style J). The claims made for this equipment are beyond the performance of the usual type of scrubbers or air washers which have been tried in the dust collection field. The author has indicated such characteristics as were available without having them verified.

34. An equipment using oil flotation which utilizes the bubble tower principle is shown as Style K (Fig. 8). This newly developed apparatus was announced and displayed about a year ago. Dust-laden air is drawn through ducts to a distributing chamber. The air passes upward through thimbles and is deflected downward by means of hooded bells passing first through water and then through a froth filter carpet. The filter carpet is obtained by frothing oil on the surface of the water. The dust trapped in the wetting agent is floated over an adjustable weir to a settling chamber. The cleaned air passes to the exhaust manifold and into the atmosphere.

35. The characteristics shown for Style K in Table 1 are

based on tests made in the laboratory of a well known technical school. These tests were made using dusts similar to that encountered in the foundry. Additional time and practice will be required to determine the full scope of application of this equipment in the foundry dust collecting field.

OTHER TYPES

36. Attempts have been made to adapt many other types of collecting equipment to foundry dust, such as the dry air filter using a paper composition filter medium, the viscous film filter, and the usual types of air washers. Little success has been met with these types of equipment in the foundry dust collecting field as they are either not suited to the type of dust, or the dust concentration is far beyond the range of the equipment. For these reasons, they have been purposely omitted from this paper. The dry air filter is effective in cleaning air for ventilating and positive pressure respiratory systems, as the viscous type filter is suitable for cleaning air to compressors. Such services are not within the scope of this paper.

DISPOSAL

37. The disposal of the collected dust often presents a real problem, as once the dust is collected it must not be liberated into the air. There are many types of equipment such as screw conveyor loaders, etc., which can be adapted to most installations. Often the dust is so fine that it cannot be transported in open wagons or cars and if air tight wagons or cars are used, the vibration in transit settles the dust so that the whole mass becomes hard and cannot easily be discharged. A method of overcoming this difficulty, which has been used quite successfully, is to discharge the dust into an agitated water tank some 2 ft. below the surface of the water, thus mixing a sludge composed of water and dust. This sludge can be readily pumped to the disposal point by suitable sludge pumps. After each pumping the sludge line should be thoroughly purged with clean water to prevent settlement in the line.

POWER AND MAINTENANCE

38. The power requirements of the various dust collecting equipments will depend altogether on the particular installation. In centrifugal collectors of the low efficiency type it may be as low as 1 H.P. per 1000 cu. ft. of air per min. and as high as 3 H.P. in

the high efficiency unit, where it is necessary to greatly increase the air velocity in the collector in order to collect a greater proportion of the extreme fine particles. In general, it can be said that the maintenance on these types of machines is relatively low, as the only upkeep involved is caused by abrasion on the collector and fan. The fan is usually protected by being placed at the outlet end of the collector, thus handling the finer and less abrasive particles. To overcome this wear, the centrifugal fan type collector has a rubber lined rotator and casing when installed for abrasive dust.

39. The power required in cloth collectors will vary from 1 to 2 H.P. per 1000 cu. ft. of air per min. depending upon the relative size of the equipment and the concentration and nature of the dust. Maintenance is relatively high because of screen and bag replacement. Also, the equipment is more elaborate as there are more moving parts to keep in repair and adjustment.

40. In the washer type collector the air velocity is relatively low with a corresponding low power requirement of 1.5 H.P. per 1000 cu. ft. or less. The water recirculated will contain relatively large amounts of dust unless large and hence expensive settling tanks are provided. Due to the small amount of water recirculated, the total cost of pump maintenance would not be high.

41. The power requirement for the oil-flotation collector is approximately 1.5 H.P. per 1000 cu. ft. The water and settling tank requirements approximate those of the washer type. Only a small amount of low cost oil is required.

Conclusions

42. In solving a foundry dust problem there are many factors to be considered. In northern climates the shop buildings are necessarily completely enclosed and the operations compact. Many of them are in densely settled communities. Such conditions demand highly efficient dust collecting equipment which in some cases might approach air-conditioning practice. In the south we find open type buildings with maximum natural ventilation in thinly populated areas. Under such conditions a much higher dust concentration can be discharged from the operations without undue pollution of the surrounding atmosphere.

43. Weight efficiencies of dust collectors are of little value unless considered along with a complete analysis of the dust to be

caught and the operating conditions. The percentage of silica has a direct bearing on the problem.

44. Some workers in the field have recommended the maximum number of particles per cu. ft. based on certain free silica content for safe atmospheric working conditions.

45. Rather than efficiency, a more satisfactory way of expressing effectiveness would be the concentration and dust count of the air exhausted from the collector. Such information can be readily obtained by various apparatus such as the impinger dust sampling apparatus as used by the United States Public Health Service. These values could then be compared with those thought to represent safe atmospheric working conditions. These data would indicate the advisability of discharging a collector into an enclosed building.

46. It is for the engineer and the foundryman to properly analyze the problem at hand, and to ascertain the degree of fineness of dust it is expected to collect before attempting to choose the collector. Since any type of collector will collect a certain amount of real fine particles, in general, it is better to have an inefficient collector than no collector at all. If the dust is collected immediately at the point of its creation, the chances are good that the dust found in the general atmosphere of the shop will be within reasonable safe limits.

(Discussion of this paper begins on page 222)

Methods of Dust Control

By J. D. Leitch,* Toronto, Canada

Abstract

Dust must arise from a source and, according to the author of this paper, the point to begin elimination of the dust hazard is at that source. In his paper, the author discusses methods used for controlling the dust hazards which originate at different types of sources. He discusses the general methods used in dust suppression problems and the estimation of the hazard, contending that the efficiency of a dust collection system is best determined by dust counts. He explains methods used for testing ventilating equipment and discusses the selection of fans. The latter section of the paper deals with the dust collection equipment itself. Dust collectors of various types and respirators such as helmets, filter type respirators and positive pressure masks are discussed. The paper closes with the admonition that maintenance of equipment is necessary to the successful operation of such equipment and to the efficiency of any installation.

1. The engineering aspects of the dust problem must deal entirely with prevention and must be concerned with manufacturing processes, production requirements, and other economic considerations. It is necessary to obtain the greatest reduction in dust concentration with the minimum capital expenditure and maintenance costs. It can readily be shown by considering a number of particular cases, that money spent to improve health conditions often has resulted in unexpected economies in the processes which more than paid for the original outlay in a very short time.

Difficulty of Laying Down General Regulations Governing the Control of Dust in Industry

2. From a public health point of view, it is desirable to lay down minimum rules covering the suppression of dust for all op-

* Ontario Department of Health.

Note: This paper was presented at a session on Dust Control and Safety Codes at the 1935 Convention of A.F.A. in Toronto, Canada.

erations in industry. Because of the wide variation in the dust producing processes in industry, it immediately becomes apparent that some attempt must be made to subdivide these processes. The first natural division would appear to be a division of the industries themselves into groups—foundries, granite cutting, mining, etc. This is hardly a satisfactory division from the point of view of the engineer whose job it is to consider all the industries.

3. When the foundry division alone is considered, a wide variety of processes is encountered, such as tumbling, grinding, sandblasting, coreblowing, shaking out, molding and brushing, but on examination of, say the granite industry, some overlapping occurs, for in that industry we find operations involving sawing, surfacing, polishing, sandblasting and chiseling. If a foundry were visited and then a granite shop, it would be seen that although some of the operations are similar, the most efficient methods of removing the dust are quite different in detail. Observations in a number of foundries show variations in type of equipment installed. An example of this may be noted in the different methods of sandblasting castings, *i. e.*, barrels, sandblast rooms, cabinets and special equipment, among which may be listed numerous homemade devices. However, in spite of these variations, a number of general cases may be considered, into which most of the common processes will fit.

CONSIDER DUST SOURCE

4. First, let us consider the source of dust as a variable condition. In other words, we should always go to the source of the dust hazard and try to suppress it there before contamination of the shop air occurs.

Point Source.

5. When the source of dust is at a fixed point, it is natural to think of using a fairly high velocity through a relatively small pipe attached as closely as possible to the point. This method is desirable from the point of view of handling the minimum amount of air but care must be taken that the hood be attached very close to the point source, because it is well known how rapidly the velocity falls off as we move away from the hood face. Should the point source move in a random way, the problem of maintaining the hood close to the point becomes difficult in some cases, *e. g.*, it is very difficult in the case of the hand pneumatic tool in the granite

industry and not so difficult in the surface machine in the same industry.

Wide Source.

6. If the origin of the dust is over a wide area one naturally thinks of two methods.

a. Enclosing the source as much as possible and then removing sufficient air to maintain the enclosure at a pressure somewhat lower than atmospheric, or,

b. Providing ventilation over a wide area. This necessarily involves a high volume of air and a relatively low velocity.

7. The former method would appear to be more feasible in cases where such enclosure does not interfere with the process.

Moving Dust Clouds.

8. If the process produces a cloud of dust having a definite direction of motion, advantage should always be taken of that fact by arranging to draw off the dust in the same direction. A simple example of this is the grinding wheel and the standard method of ventilating it. There are a number of cases, however, where this is not so easy on account of interference with the process, and ingenuity is required of the engineer who tackles such a problem.

Intermittent Source.

9. It often happens in industrial processes that a dust cloud is produced in the form of puffs at regular intervals. These clouds of dust may be so high in concentration as to render it impossible to collect all of them by means of a low volume of air at a high velocity. In such a case, it would be better to use a hood having a large area giving a lower velocity of air, so that the dust would be caught before it left the range of influence of the exhaust system.

10. From the point of view of economy, first, in the conservation of heat, it is desirable to remove a minimum quantity of air from the shop; second, from the point of view of power consumption, it is desirable to use the minimum velocity at the source of dust yet obtain conditions within the safe dust concentrations as laid down by the health authorities. Therefore, it is apparent that for every dust suppression problem, there is a best choice of air

volume and velocity according to the design of hood required by the process. What these conditions are for any particular operation, can be determined only by experiment and experience. Every foundry operator and every engineer who is concerned with the dust problem, will be required to do some experimental work which will lead to solutions of these problems for each dust-producing operation in industry. It is obvious that those men who are daily in contact with these operations, who understand the production requirements, who fully appreciate the nature of their problems, will be the most likely persons to solve them.

General Methods

11. In looking at a dust suppression problem, it is often advisable to consider a variety of methods, that is, not necessarily assume that all dust suppression problems will be most effectively solved by means of ventilation. Consideration must be given to methods involving water or other liquids as a means of settling dust. The advisability of entirely enclosing the operation or isolating it from the general shop atmosphere also must be weighed. Making certain parts of the operation automatic might be considered, thereby eliminating the necessity for workmen to stand in a dusty atmosphere; or the whole process might be changed and carried out in such a way that no dust hazards exist. A good example of this is the use of water blast in cleaning large castings. Then again consideration might be given to the materials that are used. A suitable product might be obtained by the use of a substance that produces dust which has a relatively low health hazard. This has been done in a number of cases, *i. e.,* non-silica parting, artificial grind wheels, and steel grit in blast cleaning operations.

12. These general methods are mentioned, not because they will necessarily lead to a solution of any particular problem, but to widen the approach. In other words, it should never be assumed that the only and best method has been found.

13. One of the first things that should be done in an attempt to introduce a dust control program in a particular industry, is a thorough shop cleaning, including rafters, window sills, windows, floors, walk-ways, etc. This will be a very large job, and more than likely expensive the first time, but once done, it will be found that periodic cleanings will be much less costly. As a matter of fact, a program of regular periodic shop-cleaning would serve as

an excellent indicator as to the effectiveness of any steps taken to control dust at its various sources throughout the shop. Of course, the shop-cleaning process is a very dusty one and the use of water sprays and suction devices is preferable to blowing with compressed air.

ESTIMATION OF THE HAZARD

14. It is extremely difficult to estimate the maximum permissible concentration of a particular dust in industry in keeping with the good health of the worker. It has been suggested as a tentative goal that the maximum concentration of dust containing 35 per cent silica should be not greater than 10,000,000 particles per cu. ft. below 10 microns in size. Of course, if the dust is quartz, which is 100 per cent silica, the maximum permissible concentration will be proportionately less.

15. In estimating the dustiness of an atmosphere, the present method is that of the United States Public Health Service which uses a bright field in the microscope and a magnification of 100, the sample being collected by the Greenburg-Smith impinger method. Apart from any differences in dust counting methods, and there are differences, any one of the recommended methods is quite useful in arriving at a measure of the effectiveness of a ventilating system should dust counts be made before and after its installation. A number of reports claim very high efficiency for various types of dust collectors, but the method of arriving at this efficiency is based, in almost every case, on weighing the dust entering the system and that caught by the collector. It is apparent that this method is not at all in keeping with efficiencies based on dust counts because a particle 100 microns in diameter will weigh a million times as much as a particle 1 micron in diameter; so that the efficiency of a dust collector would appear very much higher if there were any large particles in the dust fed into the collector. It is felt that the particles between 1 and 5 microns (1/25000 to 1/5000th of an inch) in diameter are biologically significant and for that reason, it becomes necessary to make dust counts rather than measure efficiencies by weights. Of course, such measurements of the efficiency of a dust collector or arrester are only of significance in a case where the cleaned air is returned to the shop atmosphere, a procedure which should not be carried out unless some type of collector

is developed which meets the requirements laid down by the methods of dust counting.

16. At the present stage of the dust problem, it would seem that the most *practical* means of diagnosing the dust hazard is the naked eye, with all due respect to dust counts. If a shop is very dark so that no dust is visible, it would be advisable to use a powerful flashlight or clean some of the windows so that the sun's rays might show up the dust. It may be that in the near future a more rapid method of estimating a dust hazard will come into general use. Let us hope that this is so, for it is quite out of the question for any but the larger firms to consider purchasing of present equipment and employing of trained personnel for regular routine tests.

17. The first problem in the removal of dust is to get rid of all visible dust for in so doing a very great amount of the invisible particles will also be removed.

TESTING VENTILATING EQUIPMENT

18. If a survey is made of the various State laws relating to dust control in the United States, a very wide variation in the requirements is found. Some statements are made demanding that the static pressure measured behind the hood should give 2 in. of water difference in level in a manometer. In another State, for the identical operation, 5 in. of water is required as a minimum (this refers to grinding wheels). There is a great difference between 2 and 5 in. of water static pressure. Assuming the hood designs to be identical in both cases this would mean a difference in the air velocities of approximately 6 to 1. There cannot be very much scientific basis for regulations which vary by a factor of 6 to 1. However, this is not the worst indictment of these regulations. The worst is that static pressure readings taken behind the hood measures the sum of two factors and does not give a measure of the velocity of air being handled by the system. The two factors are—(1) loss of head due to resistance at opening, and (2) loss of head necessary to set the air in motion.

19. If static pressure is to be a measure of the effectiveness of a dust collecting system, it is necessary immediately to specify exactly the shape and size of the hood in every particular application; a procedure which is of course out of the question. It would be far better to say that the velocity in the duct must be

not less than say 4000 ft. per min., the duct must not be smaller than say 4 in. in diameter and that the air velocity at the source must be no less than 400 ft. per min. In other words, it is necessary to define the minimum volume and velocity of air for any particular application. It is because of the ease with which static pressure readings can be taken that it has been used so much in the past, but their only value lies in observing the constancy of an exhaust system from time to time, thereby assisting in the detection of excessive fan wheel wear, belt slipping or dust arrester leaks. Care must be taken that the complete system, as far as duct inlets are concerned, is operated in identical manner at every test.

20. This immediately brings up the problem of testing and inspecting dust-removing equipment. In order to determine the most important factors, *i. e.*, volume and velocity of air handled, the use of the pitot tube in conjunction with a manometer is most suitable for the duct system; and for the measurement of air velocities below 500 ft. per min., the Kata thermometer has proven its value in many cases.

21. The American Society of Heating and Ventilating Engineers has formulated standard methods of testing fans, and these methods involve the use of a pitot tube in a definite manner. Such a procedure as recommended is too elaborate for factory inspection purposes or for the average individual in industry, but, if we neglect the refinements in measurement, the pitot tube will prove a most useful instrument in the hands of anyone who is willing to investigate his ventilating system.

SELECTION OF A FAN

22. The selection of a fan for a particular dust problem is of primary importance and, to the end that the fan manufacturer may give the advantage of his experience, a precise statement of the problem on hand is essential so that he may intelligently recommend the proper fan, of sufficient size driven at an adequate speed. The author has seen a number of foolish applications of fans and does not blame the fan manufacturer for these, as very often he is not consulted, the fan merely being purchased through a purchasing agent according to a requisition with inadequate specifications supplied by some mechanic. The ordinary propellor

fan should never be used in forcing air through a duct system which offers any appreciable resistance.

23. The choice of fan depends not only on the operation but on the type and shape of the material to be handled. Therefore, it is necessary, in asking the fan manufacturer for a quotation, that all the details be submitted with the request. The author recalls recently seeing a letter written by a manufacturer to a fan company in which he outlined the piping on a very rough sketch and he received a quotation on a particular fan by return mail. It was apparent, on looking at the sketch, that the system of ventilation would require two separate installations, as the purposes for which the fan was to be installed were of two radically different natures.

PIPING

24. If a uniform distribution of suction is to be maintained, it is very necessary that the piping be properly proportioned. The author once went into a foundry in which a 15 in. diameter pipe ran directly over a number of tumbling barrels. From this 15 in. pipe, a 3 or 4 in. pipe ran down to each barrel. A number of manholes had been cut in the pipe and, on inquiry, it was found that every two or three weeks, the big pipe had to be opened and emptied. The cost of this work probably would have paid in a short time for the proper proportioning of the piping, apart from any gain in efficiency of the ventilating system.

25. The use of dampers at the various inlets of a ventilating system may seem very feasible from the point of view of controlling the air movement and is undoubtedly of value in adjusting improperly designed piping installations; but if an installation is properly designed, the use of dampers will be entirely superfluous and will serve only to upset the system.

DUST COLLECTORS

26. Four or five main types of dust collectors are in common use today. First, and perhaps the most common, is the ordinary cyclone. This type of dust collector is far from efficient in the removal of fine particles and under no condition should the exhaust from it be returned to the workshop nor should its exhaust be located near an open door or window. The second most common type in use is perhaps the cloth screen or cloth bag type. For a number of years, this type has held the foremost position as a

collector of fine dust, but the author knows of no tests that have been made regarding its efficiency on a dust counting basis and it is advisable that such tests be carried out. Often the claims made by the manufacturer would indicate that such a dust arrester would permit of the air being returned to the room. It may be quite true that when an arrester of this type is new its efficiency is high but there is certainly no assurance that it will continue to function in that manner.

27. Another type of arrester that apparently is gaining ground is the centrifugal type in which the fan is so designed and driven at such a high speed that the dust is thrown out at the periphery and collected by centrifugal force. Any test information which the author has seen on this type of collector, has always been taken on a weight basis, which is anything but adequate from a health point of view.

28. Considerable work has been done in the past few years on the problem of smoke abatement and in this work some new designs of gas washers have been developed. There is a similarity between these gas washers and some new designs on dust collectors of the water type. In one machine, the dust laden air impinges on a series of wet baffle plates as it passes upwards through the collector. The author often has considered the principle of the Greenburg-Smith impinger type of dust sampling apparatus to possess a principle worth investigating with a view to its adoption in dust collector design. One of the great difficulties in gas washers developed for the smoke abatement problem has been the high consumption of water. It has also proved expensive to recirculate the acidified water. This should be a much easier task in collecting silica dust.

29. Many applications in industry do not provide any dust collection whatever as the amount of dust does not warrant such expense nor does the location require that the exhaust air be absolutely clean. In the author's opinion, it would be far better to use no dust arrester and exhaust the air containing the dust high into the atmosphere than to install a dust arrester of low efficiency and re-circulate the air back into the shop.

30. The choice of a dust arrester, although important, is not the most important problem. The main problem is catching the dust at its source and carrying it through a duct system to a point where its disposal can be safely effected.

31. It is well known that the use of dust arresters often pays for itself over and over again if the product being collected is at all valuable. In a recent case the amount of material collected in three months more than paid for the complete installation since the material collected was worth about 10 cents per lb.

32. In choosing a cloth type of dust arrester, the most important factor (assuming a good grade of cloth) is the ratio of cu. ft. of air handled to the sq. ft. of cloth through which the air must pass. It is recommended that this ratio be not more than 3 or 4 to 1 in the collection of silica dust in foundry practice. This ratio may be increased slightly as dust concentrations drop but it is important that it be kept as low as economically possible. The author once was called out to investigate the reason why no air was being delivered by a unit heater. The unit heater had a capacity of 3000 cu. ft. per min. and was equipped with a propeller fan. On investigation, it was found that the 24 in. square duct had a sheet of cheesecloth, mounted on a wooden frame, inside it so that the ratio was 750 to 1. The owners were amazed when told that they could not get air through cloth like that.

RESPIRATORS

33. The subject of respirators is one of considerable importance in dust control. It is not meant that the use of a respirator is a desirable solution, for it is well known that most workmen would rather "take a chance" than suffer the inconvenience of wearing a respirator. Many dust producing processes in industry do not lend themselves readily to effective ventilation by means that are at all economical, and it becomes necessary to rely upon some type of protective device worn by the workman. Perhaps the outstanding process of this type is sand-blasting, but here the problem is further complicated by the danger of injury from the bounding abrasive, which makes it necessary not only to provide safe-guarding of health, but protection from cuts.

34. Respirators, in a broad sense, may be divided into three classes:—

a. Helmets.

b. Filter Type Respirators.

c. Positive Pressure Masks.

Some of the fundamental considerations in the choice of a suitable respirator may be summed up as follows:

Helmets

35. Where dust is at all hazardous to health, it is essential that all helmets be supplied with air at a positive pressure, preferably from a source of fresh air, rather than from the compressed air lines. The amount of air required by a helmet depends on the design of the helmet itself, and how it is to be worn by the operator. A loosely fitting helmet will require considerably more air per minute than one which fits rather tightly over the face or neck of the workmen. In general, the amount of air should be sufficient to maintain the positive pressure within the helmet throughout the entire breathing cycle of the workman, so that at no time will air be drawn in through any crevices. A sufficient pressure inside the helmet should be 2 or 3 ounces above atmospheric and an adequate volume of air should be about 6 cu. ft. per min. Of course, it is not meant that this air volume will develop sufficient pressure inside a helmet in every case, especially if the helmet is a loosely fitting one.

36. A helmet should preferably be designed in such a way that its weight rests on the shoulders thereby permitting a free movement of the man's head. The air line attached to the helmet should be firmly fastened to the man's body, so that he will experience no inconvenience in moving it about inside, say, a sandblast room.

Filter Type Respirators

37. The main requirement of any filter type respirator is that the rate of flow of air through the filter medium be as low as possible, for if the workman must exert himself in breathing, considerable dust will be pulled through the filter. This would mean that the filtering medium should present as large an area as possible, and the main problem becomes one of convenience in wearing an apparatus which must present so large an area.

38. A filter mask, which is efficient, will naturally plug up sooner than one which is inefficient, and it is essential, both from the point of view of economy, and efficient health protection, that the filtering medium may be readily replaced or cleaned.

Positive Pressure Masks

39. It is undoubtedly true that a positive pressure mask is far superior to any filter type, but it requires a supply of air. Many

companies who use such masks attach them to their compressed air lines through an adjustable reducing valve, and the objection is raised by the workman that the air smells of burnt oil and contains considerable amount of water vapour. Both of these objections can be overcome by the use of a small blower which will provide an adequate supply of air at a sufficiently high pressure from a source that is free from contamination. There is considerable room for development of a cheap and effective blower designed for use with fresh air masks. The use of air filters and after-coolers in the compressed air lines presents another approach to this problem.

The Importance of Maintenance

40. Machines, like everything else in this world, wear out; and the essential parts must be replaced by new ones from time to time. This is particularly true of fans, especially when there is abrasive dust in the air which they handle. The author has found fan wheels in such installations completely worn out, the ventilation system practically useless and the driving of the fan merely a waste of money. Regarding dust arresters, especially of the cloth type, great care must be taken to maintain them or they will plug up and develop such a high resistance that the air cannot get through them, with the result that eventually the cloth tears away from its support and large quantities of dust come out of the clean air side. Dust arresters should be cleaned at regular intervals, better often for short intervals than for long intervals at less frequent times. One naturally should consider how to reduce the maintenance costs and it is proposed that every man who has installed a fan and dust arrester should look and see whether the dust arrester or the fan comes first in the ventilating system. If the fan, he should change it and save the wear on his fan wheel. This may seem like a very obvious remark, but in many instances this point has been neglected with the result that the fan wheel was completely worn out in a relatively short time.

General Conclusions.

41. It might be well to sum up with a few general conclusions:

1. No source of dust is too insignificant for attention.

2. Any efforts made to control dust will probably result in other economies being effected.

3. A dust problem requires not only cooperation of employers, but of employees as well, in a conscientious effort to control the dust hazard.

4. There is always a best way of handling a given dust problem, and this can usually be determined only by experiment in the application of fundamental principles.

5. Apart from all dust counts as a means of indicating the relative hazards in industry, the ultimate test of the effectiveness of the dust control can be determined only by medical examination. Therefore, it is a necessary part of any dust control program that periodical examination be made of all workmen engaged in dusty atmospheres.

(Discussion of this paper begins on page 222)

DUST CONTROL — DISCUSSION

P. J. POTTER[1]: In Mr. Moxley's paper, paragraph 11, it is stated that the proper air velocity to handle ordinary foundry dust would be between 2500 and 3000 ft. per min. I would like to ask Mr. Moxley if they had long horizontal pipe runs, because it has been our experience and, I believe, common practice, to keep the pipe velocity about 3500 ft. per min.

MR. MOXLEY: We have found, with the amount of dust in our plant (and we are talking about the dust as indicated by the curves on the slides I have just shown) that between 2500 and 3000 ft. per min. will prevent clogging of the dust line. It is most important to reduce the duct at each intake and correctly design the duct as it goes along through the shop. We have one duct 48 in. in diameter and gradually reduce it to 12 in. in diameter. Its horizontal length is about 200 ft., and we do not have clogging. Our velocity is kept maybe closer to 3000 than 2500 ft. per min. but it plays between those figures.

MEMBER: Would moisture in the air affect the 2500 to 3000 ft. per min. velocity of which Mr. Moxley speaks?

MR. MOXLEY: We have made a complete analysis of our dust and it shows approximately one per cent moisture. Of course, as the moisture increases, it may go beyond the range of a cloth collector. As moisture increases, it is more and more difficult to handle the dust without clogging the pipes and the velocity should be increased.

MEMBER: It has been intimated in one of the papers that manufacturers of dust collectors have recommended a return of the air into the shop after it has passed through the exhaust system. I would like to correct that impression. I believe I am correct in saying that manufacturers of dust collectors with whom I am acquainted have not for some years past recommended the return of any of that air to the shop.

DR. J. T. MACKENZIE[2]: I would like to ask Mr. Allan whether he has any data on the washer type collector to indicate the retention of the fine particles. After listening to the discussion at the health hazards session this week and that today, it is quite apparent that the harmful size of the dust particles lies somewhere between half a micron and ten microns. You could have collection which is 99.9 per cent efficient by weight of the dust collected without taking out very much of the fine material. If the dust which is being put into the collector is 99.5 per cent above ten microns, you could have that efficiency without doing a bit of good, if you do not take out the fine particles.

J. R. ALLAN*: In answer to Dr. MacKenzie, we have not made any test on the efficiency of such collectors that we have installed. Where we have them on the foundry shakeouts and the tumbling mills, the set-up is so we are unable to get a reasonable sample and we have made no attempt to make the tests referred to by the first speaker. We have some cloth collectors on carburizing materials and these showed consider-

[1] Pangborn Corp., Hagerstown, Md.
[2] American Cast Iron Pipe Co., Birmingham, Ala.
* International Harvester Co., Chicago, Ill.

able evidence of dust in the discharge stack. The wet collectors on the same type of work indicated no visible trace in the discharge stack.

MR. LEITCH: I wish to correct an impression that I may have given. I said that as a *practical* measure in the immediate future in our attack on the silicosis problem, the use of the naked eye in determining atmospheric dustiness would seem the most practical thing to do. From the point of view of measuring the efficiency of dust collectors, I would be much more in favor of dust count by standard methods in terms of micron sizes.

DR. MACKENZIE: As I understand it, the dust you see does not hurt you. Is that right?

MR. LEITCH: That may be true and is true, of course, of the larger particles. I am sure that if you have a large cloud of fine particles you can see them, though not individually, especially if contrast in light exists in the shop.

DR. MACKENZIE: The point I am making is that the dust collector will render air, which though perfectly invisible, may be very dangerous, especially if you return the air to the shop. The type of collector that takes out only the visible dust, returns all the harmful dust to the shop.

MR. LEITCH: At no time did I recommend having the air returned to the shop.

MR. MOXLEY: I would like to say a word regarding the checking of a dust hazard by the naked eye. It is quite generally recognized that you can barely see a particle of over ten microns in diameter. A micron is 1/1000th of a millimeter.

Most of the workers in the medical field claim that the upper limit really is about eight microns. I have heard of one case where the worst dust hazard in the plant was in the core room where there was no visible dust at all.

That is the reason I put a great deal of dependence upon weight efficiencies and dust counts in analyzing the effectiveness of a dust collector. I still believe the weight efficiency method is a fairly good measure but only when considered along with all of the other characteristics that are available.

H. L. MCKINNON[3]: On the question of the dust count in our plant, we have made upward of two hundred tests in the past four months, involving the actual dust count from a wet collector. We have, at the present time, three large machines in operation, two of which have been tested for dust count. The question of what the final dust count will be, we find, bears very close relation to the fineness of the dust when at the source because you will get a percentage of the fines on any of these collectors.

We found, for instance, in getting dust which was swept off the beam of a foundry and tested, that we got a very high rate of efficiency and a comparatively low dust count with that material.

Then we tried some silica flour which had been ground under 325

[3] C. O. Bartlett & Snow Co. Cleveland, O.

mesh, 92 per cent of which was less than five microns, and we found that the dust count went up materially with the same loading.

We found an analysis of some of the dust swept off the rafters indicated that the dangerous dust was not more than 20 per cent of the total dust, about 80 per cent being above the ten micron size.

We have not gone far enough along yet to give anyone any final conclusion on this. We do know that we can get within the range of reasonable cleanliness with the wet collector and we do know that the dust count will vary definitely with the nature of the dust that is fed into the system.

I want to make one remark in regard to Mr. Moxley's paper, namely in the tabulation of the wet collector, he made the statement that the maximum loading be 25 grains per cu. ft. That we feel is not strictly so; we have used much higher loadings than that in certain instances. I am satisfied we can take any loading. It depends entirely upon the fineness of the product and I would not want to take 25 grains per cu. ft. of 325 mesh material into a machine. I would not want to guarantee the condition on the output of that machine. The fact is, it is going to be possible and is possible now to get a reasonable dust count with the wet process.

W. G. FRANK[4]: Working in both the dust collecting and the air filter field, I must say I have enjoyed the various papers very much. There have been many interesting details given which should furnish an incentive for further thought and development in dust collecting practices for the best interests of everyone concerned, especially the workman who is handicapped in some instances by difficult conditions.

It is quite definitely true, if a manufacturer takes steps to introduce dust collecting equipment in his plant he will not only have the satisfaction of improving sanitary conditions but he will also reap a definite benefit in improving his production and in reducing his costs.

F. A. EBELING[5]: It has been inferred that dust collectors might be sold just for the sake of making sales without taking actual conditions in the foundry or any other manufacturing plant into consideration.

I do not believe that is so with established manufacturers of dust collecting apparatus. None of them, including ourselves, would make any kind of a recommendation unless we were pretty sure as to what was to be accomplished.

In other words, when we are making a recommendation for equipment, whether by invitation or otherwise, we would not make any recommendation for size of collector, or size, speed or power of fan, unless we knew in considerable detail what the dust collector should do.

We must know what a collector should do. Neither we, nor any other manufacturer, can back up an installation recommended unless we are sure that the pipe system, the hood system, etc., are designed properly. Many times we have no control over the installation of hoods and pipes, yet we feel it our duty to ascertain beforehand that hood and pipe conditions and construction are correct. I believe that people who have dust

[4] American Air Filter Co., Louisville, Ky.
[5] W. W. Sly Mfg. Co., Cleveland, O.

problems may go to any established manufacturer with confidence that the recommendations made by the manufacturers will be in accordance with the problems presented.

CHAIRMAN E. W. BEACH[6]: I do not think that there is any question as to the soundness of the ethics of the manufacturers involved, which led to Mr. Ebeling's rebuttal. I think, rather, the statement mentioned was meant to convey that very often a plant manager or his mechanical superintendent simply requests the purchasing department to order some fan, without the purchasing agent or anyone else knowing for what purpose the fan is to be used.

I believe there is no doubt, if the master mechanic had told the purchasing agent that he wanted a fan for a special use as applied to a certain problem of removing dust, and his requirements passed on to the manufacturer, he would have been given full information and probably many questions would have been asked before apparatus was shipped.

E. H. BALLARD[7]: I think a little more consideration might be given to some of the facts brought out by Mr. Leitch.

This is absolutely a cooperative proposition. We as foundrymen, have a distinct responsibility. I recall that in the early days of dust collecting we, ourselves, had been sold equipment that through lack of knowledge was guaranteed to do certain things without specific measurements. I think the time has come when any equipment manufacturer selling equipment to perform a certain job should not undertake a sale until he knows all the facts. Unless he does, the equipment so installed is absolutely useless to accomplish the purpose for which it was installed.

Salesmen differ. Some want sales and some want to put equipment in to perform a certain function they agree that it will do. So, I say again, I believe that the equipment men have to work closer to the foundrymen to know what the problem is. In my opinion when a piece of equipment is installed, it should be subjected to the same type of test as we are going to be subjected to by the health authorities in coming into the foundry and analyzing our dust and our conditions. Equipment so purchased should meet specifications agreed upon, based on and subjected to tests and methods used by state and insurance inspectors in determining dust counts.

Incidentally, I believe the manufacturers are going to have to perform a service which they so far have given to us only when requested, and then, probably, in only a superficial way. I think they will have to have a service and come in and check us up to see that the equipment is just where it belongs, the same checking we receive from our state inspectors. In other words, we have to be a little ahead. That is going to cost money, but it will be of untold value to foundries where they do not have a mechanical organization with sufficient knowledge to keep the equipment up. We need help, some of the larger plants as well as the smaller, but particularly the smaller ones. Any improper operation of

[6] Engineering Executive, Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

[7] General Electric Co., West Lynn, Mass.

the smaller foundries is a reflection on the larger ones and on the operations of the industry as a whole.

So, I say again, I think we as foundrymen are going to appeal to the manufacturer to work with us and I think they, in turn, should demand to know of us what our true conditions are. Then between the two, I am sure we are going to make tremendous strides in overcoming a hazard that without doubt exists.

MR. LEITCH: The problem of loss of heat is a very important one and one that costs a considerable amount of money. In the ventilating of the tumbling barrels, for instance, I believe the air enters at one end and goes out through a pipe at the other end. Why not pipe in the air ventilating the tumbling barrels the same as you pipe the dusty air out? I know installations where 10,000 cu. ft. of air per min. are being taken from the shop which would mean a considerable saving in heat if the air were not taken from the shop but brought in from the outside.

Regarding sand blast rooms which in many cases require ten or even twenty thousand cu. ft. of air per min. in their ventilation, I do not see why such equipment should or could not be ventilated in a similar manner, *i. e.*, by bringing the air in from outside. The only objection I can see is that the man might feel rather cold in the winter time, but I am sure he would enjoy it in the summer time. In the winter time it is not necessary for a man so well clothed as the man in the sand blast room, to have as high a temperature of air as the man in the shop. After all, the man in the sand blast room is a very busy man and therefore does not require such a high temperature on the very cold days when it is 20 or 30 degrees below zero. I think it would be quite feasible to install heating coils to take the chill off the air when necessary.

I place these points before you for your consideration. I have not yet seen an installation to which these considerations were given.

There is another point and I have often wondered why advantage of it has not been taken; that is, the sand blasting of castings in a more automatic way, with the man standing external to the apparatus. I refer to the granite industry where they sand blast and the man always stands outside. When you understand that dust conditions such as prevail inside sand blast rooms are of the order of 2,000 or more, million particles per cu. ft., it becomes of some importance that the operator preferably stay outside. I think we may all look for the development of sand blasting machinery in which the man does not enter the room.

DR. J. G. CUNNINGHAM[8]: I am very interested in this problem of the extent of the dust in the air. It does seem to me to be unfortunate that the impression was left that any of us would depend on eyesight entirely for estimating the dust hazard.

I am sure Mr. Leitch, in his discussion of the subject, was referring to gross exposure to dust. In a great many instances where dust is visible there is fine dust also. I do not think that anyone familiar with the subject would undertake to say that there was no health hazard because they could not see any dust, particularly if they knew that the

[8] Department of Health, Province of Ontario, Toronto, Can.

processes might emit fine dust into the air. It is quite possible to have a health hazard from silica and not be able to see the dust.

It is true that in indirect light one can see the evidence of dust where it would not be seen in ordinary light. I do think it is important, in discussing estimation of dust concentration to understand that we are referring only to gross exposures.

C. J. HEATH[9] (*Submitted in Written Form*): In testing the efficiency of various types of centrifugal dust collectors, it is essential that each dust collector be tested under identical conditions, preferably on the same problem. To state in one case that 50 per cent of the dust collected passes through a 325 mesh screen in one locality may mean something entirely different to say that 50 per cent passes a 325 mesh screen in another locality. In one case, the 50 per cent passing may mean on down through a 2500 mesh screen on which no type of centrifugal separator would be very effective, and in the other case, the 50 per cent passing 325 mesh may show that that passing would all be retained on a 400 mesh screen on which a high efficiency centrifugal collector would show very favorably.

[9] Research Corporation, New York, N. Y.

The Control of Cupola Operation

By H. L. CAMPBELL* and JOHN GRENNAN**, ANN ARBOR, MICH.

Abstract

Cupola control always has been an interesting subject to foundrymen and one which has been discussed a great deal. In this paper, the authors divide the cupola into four zones, explain the functions of those zones and the reactions that take place. The authors then discuss melting ratios, cupola bed height, metal and coke charges, fluxes and air supply. The authors conducted experiments to determine the penetration and distribution of the air supply in the cupola. A series of measurements were made with the air and coke bed at room temperature and the authors admit that under actual operating conditions, the expansion of the gases probably would influence the results to some extent. On the basis of the results obtained from this investigation, the authors reach the conclusion that there is little, if any, advantage to be gained in the distribution of air in the cupola by restricting the area of the cupola above the tuyeres or by reducing the size of tuyere openings.

1. The cupola furnace is the most widely used melting unit for cast iron and the best results from its operation can be obtained only when all divisions of the practice are under definite control. In the following discussion, attention is given to the combustion conditions within the cupola and to the proportioning of the metal, fuel, flux, and air supply. A definite amount of air may be supplied to the cupola, containing sufficient oxygen to burn a definite weight of coke which in turn will produce sufficient heat to melt and superheat a definite weight of metal. Furthermore, a definite weight of flux is necessary to obtain satisfactory slagging conditions. When the correct proportions of air, fuel, flux, and metal are used, reliable and uniform melting conditions are obtained in the cupola.

2. The entire shaft of the cupola may be divided into four sections for convenience in examining the operation of this furnace.

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NOTE: This paper was presented at one of the Cast Iron Shop Course Sessions at the 1935 Convention of A.F.A., Toronto, Canada.

The upper part of the cupola from the sill of the charging door to the top of the shell is known as the stack. This section serves only for the removal of waste heat and gases from the cupola. Zone *A* extends from the charging door to the top of the coke bed. Within this volume, the coke and metal charges are preheated by the ascending gases. On account of the deficiency of oxygen in the gases in zone *A*, practically no combustion of the coke takes place in this section. The heat in this region is sufficient to dissociate the limestone flux into lime and carbon dioxide, and to melt some thin pieces of scrap metals. Near the bottom of zone *A* the temperature of the gases is about 3,000 degrees Fahr., and the temperature decreases as the gases travel up through the charges. At the level just below the charging door, temperatures of 800 to 1500 degrees Fahr. have been obtained.

3. The bottom of the tuyeres locates the lower level of zone *B* as shown in Fig. 1. Maximum combustion of the fuel takes place within this section. Furthermore, the charges are so arranged that most of the melting and superheating of the metal occurs in the upper part of zone *B*. The lower portion of the interior of the cupola from the bottom of the tuyeres to the sand bottom is the crucible. Molten metal and slag collect between the pieces of coke within this volume. Since practically no combustion takes place below the tuyeres, it is impossible to add heat to the metal which is retained in the crucible.

COMBUSTION CONDITIONS IN THE CUPOLA

4. When the cupola is in operation, air is delivered at a relatively low pressure into a bed of hot coke in the lower part of the cupola. Additional fuel is supplied in the coke charges to preheat, melt, and superheat the succeeding metal charges. Combustion is maintained by the chemical reactions which take place when carbon and oxygen are brought together at relatively high temperatures. The conditions for supporting combustion are not ideal because the materials used for this purpose are not in the pure, elementary form. Foundry coke usually contains about 90 per cent by weight of carbon, and the oxygen content of air is only 23.1 per cent by weight. Therefore, some provision must be made for the removal of the ash after the coke is burned. Furthermore, the nitrogen in the air supply decreases the intensity of the heat developed by the oxidation of the carbon in the coke. However, the heat efficiency of the cupola is high compared with other melting furnaces because

the products from the combustion of the fuel come in direct contact with the materials being melted, and the counter flow of gases and melting stock permit the recovery of much of the heat produced within the cupola.

Combustion Reactions.

5. At the high temperatures encountered in the bed of a cupola furnace, the oxygen in the air supply combines with the carbon in the coke to form carbon dioxide. The chemical reaction for the complete combustion of carbon is as follows:

$$(a)\quad C + O_2 = CO_2 + \text{heat}$$

This equation implies that 12 lb. of carbon will combine with 32 lb. of oxygen to produce only carbon dioxide with an evolution of heat. The complete combustion of one pound of carbon requires 2.66 lb. of oxygen, and develops 14,550 B.t.u. of heat.

6. Another chemical reaction which occurs to some extent in normal cupola operation is indicated by the following equation:

$$(b)\quad CO_2 + C = 2CO - \text{heat}$$

This secondary reaction takes place when the carbon dioxide which was formed by complete combustion comes in contact with more carbon at high temperatures. For every pound of carbon consumed in this way, 5850 B.t.u. of heat are absorbed from the reacting materials. Hence, the conditions which favor this reaction are avoided as much as possible in cupola practice.

7. When the cupola blower is operating, the air which enters the tuyeres encounters the hot coke in the bed and soon becomes heated. Combustion of the coke proceeds more rapidly as the air passes up through the coke in the bed. If the bed is of sufficient height, a location is reached at which the oxygen in the air is completely consumed by combustion to carbon dioxide according to reaction (*a*.) As the carbon dioxide thus formed continues to travel past more hot coke, some carbon monoxide is produced according to reaction (*b*). If the height of the coke bed and the rate of the air supply are properly adjusted, this heat-consuming reaction proceeds only to a minimum extent.

8. In Table 1, the conditions resulting from the combustion of carbon are arranged in eleven groups based on the proportions of carbon dioxide (CO_2) and carbon monoxide (CO) finally produced from the combustion reactions. The analyses of the gases associated

Table 1

Air Required for Different Combustion Conditions

Combustion Condition	Percent Weight of Carbon Burned Initially CO_2	Finally CO_2	Finally CO	Gas Analysis Percent Volume of Gases CO_2	CO	N_2	Lb. O_2 per Lb. C	Lb. Air per Lb. C	Cu. Ft. Air* per Lb. C	Cu. Ft. Air* per Lb. Coke (90 Percent C)
A	100	100	0	21.0	0	79.0	2.66	11.5	151	136
B	95	90	10	19.7	2.1	78.3	2.53	10.9	143	129
C	90	80	20	18.3	4.5	77.2	2.39	10.4	136	123
D	85	70	30	16.6	7.1	76.3	2.26	9.8	128	115
E	80	60	40	15.0	9.9	75.1	2.13	9.2	121	109
F	75	50	50	13.0	13.0	74.0	2.00	8.7	113	102
G	70	40	60	10.9	16.6	72.5	1.86	8.1	106	95
H	65	30	70	8.7	20.3	71.0	1.73	7.5	98	88
I	60	20	80	6.1	24.6	69.3	1.60	6.9	91	82
J	55	10	90	3.2	29.4	67.4	1.46	6.3	83	75
K	50	0	100	0	34.7	65.3	1.33	5.8	76	68

*Air calculated at 60 degrees Fahr., and 14.7 lb. per sq. in. pressure.

with the different combustion conditions, as given in Table 1, were found by transposing the weights of the products to proportions by volume. With condition *A*, all the carbon is burned to carbon dioxide, and according to the reaction for complete combustion, 2.66 lb. of oxygen are required to burn one pound of carbon. This weight of oxygen (O_2) is equivalent to 11.5 lb. of air or 151 cu. ft. of air at 60 degrees Fahr. and 14.7 lb. per sq. in. pressure. If the coke contains 90 per cent carbon, 136 cu. ft. of air will be necessary to burn one pound of coke. With condition *K*, all the carbon is finally burned to carbon monoxide (CO) and one-half as much air is needed as is required for combustion condition *A*. With condition *F*, equal amounts of carbon are finally burned to carbon dioxide (CO_2) and carbon monoxide (CO), and the reactions require 2.00 lb. of oxygen (O_2) [(2.66 x 0.50) + (1.33 x 0.50)]. This is equivalent to 102 cu. ft. of air for every pound of coke containing 90 per cent carbon.

Gas Analyses

9. The combustion condition within any cupola can be established by the analysis of the cupola gases. With good cupola practice, the proportions by volume of carbon dioxide and carbon monoxide in the gases just below the charging door will be about equal. The gas samples from cupolas operating under favorable conditions will contain about 14 per cent carbon dioxide (CO_2), 12 per cent carbon monoxide (CO), and 74 per cent nitrogen (N_2). The carbon monoxide content of cupola gases is seldom greater than 20 per cent by volume. On the other hand, the analyses of cupola gases seldom show less than 7 per cent by volume of carbon monoxide, unless auxiliary air is introduced above the coke bed.

MELTING RATIO

10. The total heat produced from the complete combustion of one pound of carbon is 14,550 B.t.u. or of one pound of coke containing 90 per cent carbon, is 13,095 B.t.u. (14,550 x 0.90). If the conditions are such that only carbon monoxide (CO) is produced from the combustion reactions, the total heat developed from each pound of coke will be 3915 B.t.u. [14,550 — 5850) ÷ 2 x 0.90)]. The amounts of heat produced from one pound of coke for other combustion conditions are given in Table 2. Under combustion condition *F*, 75 per cent of each pound of carbon is burned initially

Table 2

METAL TO COKE RATIOS FOR DIFFERENT COMBUSTION CONDITIONS

Combustion Condition	Heat Produced per Lb. of Coke (90 Percent C), Btu.	Lb. Iron Melted per Lb. of Coke and Superheated to 2550°F.	2650°F.	2750°F.
A	13,095	14	14	13
B	12,087	13	12	12
C	11,259	12	12	11
D	10,341	11	11	10
E	9423	10	10	9
F	8505	9	9	8
G	7587	8	8	7
H	6669	7	7	7
I	5751	6	6	6
J	4833	5	5	5
K	3915	4	4	4

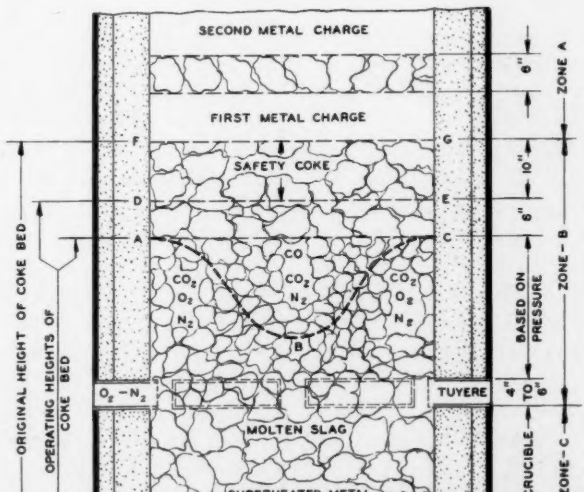

FIG. 1—CROSS SECTION OF A CUPOLA DIVIDED INTO ZONES.

to carbon dioxide with the development of 10,912.5 B.t.u. of heat (14,550 x 0.75), and the remaining 25 per cent reacts with the carbon dioxide gas to produce carbon monoxide with 1462.5 B.t.u. of heat (5850 x 0.25) absorbed as a result of this reaction. Therefore, the net amount of heat available from one pound of carbon when burned under combustion condition *F* is 9450 B.t.u. (10,912.5 —1462.5) and from one pound of coke is 8505 B.t.u. (9450 x 0.90).

11. The amount of heat required to melt one pound of cast iron and to superheat this metal to any desired pouring temperature is given in Fig. 2. When the iron is tapped from the cupola at 2550 degrees Fahr., 460 B.t.u. of heat will be necessary for each pound of metal.

12. To determine the number of pounds of cast iron which can be melted with one pound of coke in the cupola, it is necessary to establish the proportion of the total heat which is used for preheating, melting, and superheating the metal. Other uses of heat in the cupola include heating the gases and the coke in addition to the preheating and dissociation of the limestone. Attempts have been made to establish the heat balance for the cupola furnace, and the results have shown that about 50 per cent of the actual heat produced from the combustion of the coke is used in heating and melting the metal charges.[1] As 8505 B.t.u. are produced from one pound of coke under combustion condition *F*, 9 lb. of metal can be melted and superheated to 2550 degrees Fahr. with 50 per cent of the total heat produced from the coke [(8505 x 0.50) ÷ 460].

13. In case a greater heat efficiency is obtained or a larger amount of heat is produced as a result of more favorable combustion conditions, the ratio of pounds of metal melted per pound of coke will be increased. The heat produced from one pound of coke and the number of pounds of metal which can be melted and superheated to each of three different temperatures under the specified combustion conditions are given in Table 2. When steel scrap is used in the metal charges for the cupola, some carbon is absorbed by the steel, and the number of pounds of metal melted for each pound of coke will necessarily be less than is possible when only pig iron and iron scrap are used in the cupola charges.

14. The coke bed is made sufficiently high so that all melting of the metal charges will be confined to that portion of the cupola

[1] Hurst, J. E., *"Melting Iron in the Cupola."* Penton Pub. Co. 1929, pp. 111-118.

in which there is no free oxygen. The production of iron of good quality by this method of melting depends to a large extent upon maintaining the correct height of the coke bed throughout the entire heat. When the bed is too low, the oxygen in the air supply will not be completely consumed by the coke in the bed, and will

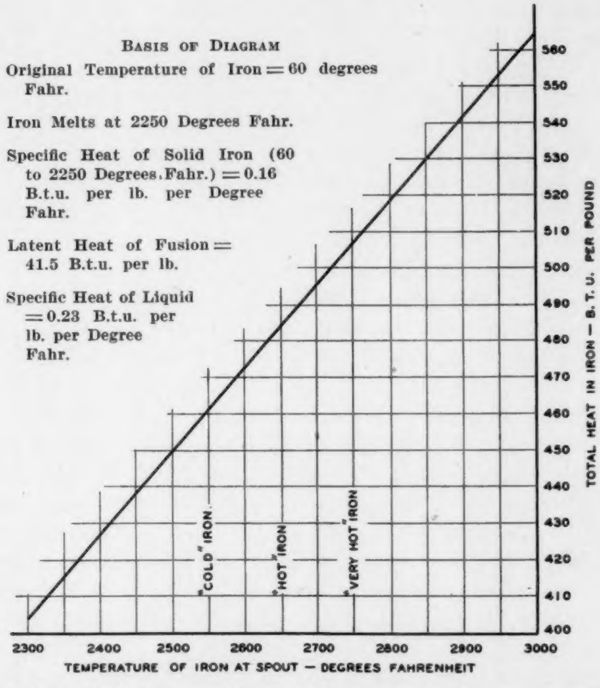

FIG. 2—TOTAL HEAT REQUIRED TO MELT ONE POUND OF CAST IRON AND TO SUPERHEAT THE METAL TO ANY DESIRED POURING TEMPERATURE MAY BE DETERMINED FROM THIS CHART.

pass up through the metal charges causing the rapid oxidation of the metal. If the coke bed is higher than is necessary for the complete consumption of the oxygen, the carbon dioxide formed initially will combine with more carbon in the upper part of the bed to produce carbon monoxide. This reaction will prevent the development of the maximum amount of heat from the coke in the top portion of the bed and will retard the melting.

15. An extensive investigation on the conditions of combus-

tion within a cupola furnace was made in 1913 by A. W. Belden[2] of the U. S. Bureau of Mines. The compositions and temperatures of the gases were found at many points within the coke bed of a cupola. From the results of these determinations, the area which located the points of highest temperatures in the fuel bed was found to have the shape of an inverted cone with the base intersecting the cupola lining 20 in. above the top of the tuyeres, when the air was supplied at a pressure of 5.3 oz. per sq. in. The line *ABC* in Fig. 1 locates the cross section of the area of highest temperature in the coke bed. Below this area free oxygen is present in the gases. To melt the metal charges without excessive oxidation, all melting must be completed above the level in which oxygen is present in the fuel bed of the cupola. The exact location of this area which is represented by the straight line *AC* in Fig. 1 is dependent upon the veolcity of the gases or indirectly on the volume of the air supplied to the cupola.

16. The investigations which have been made of combustion conditions within the fuel bed of the cupola furnace have shown that the oxygen in the air supply is gradually consumed as it passes through the hot coke bed. A certain amount of time is required for the oxygen to combine with the carbon, and the distance that the oxygen travels before it is completely burned to carbon dioxide depends upon the velocity of the gases. This in turn is controlled by the volume of air delivered to the cupola. An increase in the volume of the air supply causes an increase in the pressure in the wind belt, with other conditions constant. Since the air pressure can be readily measured, the location of the region of minimum oxygen in the coke bed can be established most conveniently on this basis. The line *AC* in Fig. 3 indicates the minimum operating heights of the coke bed for all pressures in a cupola of any size. The points on the line *AC* were computed on the basis of the increase in the velocity of the gases over that used by Belden to obtain a height of 20 in. above the top of the tuyeres for the location of minimum oxygen.

17. It is important that all melting of the metal charges be confined above the line *AC,* Fig. 3, where practically no oxygen is present in the gases. The line *DE* locates the top of the 6-in. layer of coke which will replace the coke consumed in the development of heat for melting and superheating the first metal charge. To com-

[2] Belden, A. W., *"Foundry-Cupola Gases and Temperatures,"* TRANSACTIONS A.F.A., Vol. 21, pp. 1-33, 1913.

pensate for the settling of the bed, as well as for the consumption of fuel from the time the coke bed is measured until the blower is started, the bed is increased by an additional height of 10 in. of coke which is known as safety coke. Under normal operating conditions, the height of the coke bed varies between points on the line *DE* and points on the line *AC* which correspond with the operat-

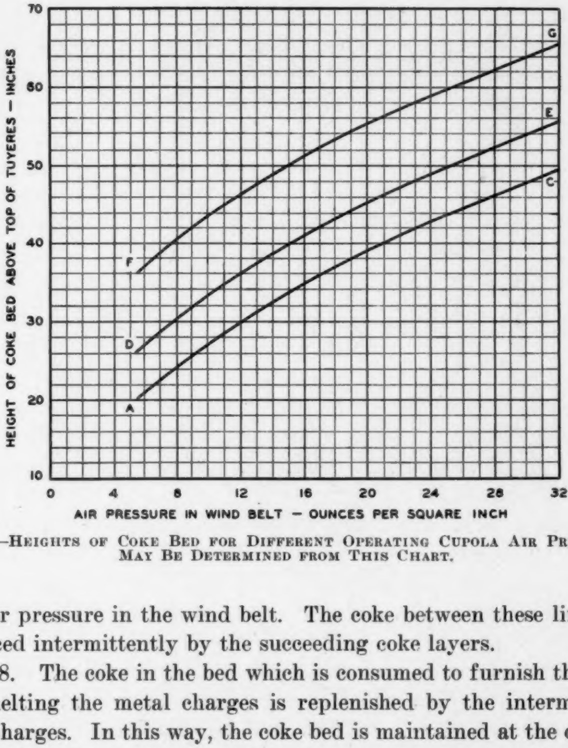

FIG. 3—HEIGHTS OF COKE BED FOR DIFFERENT OPERATING CUPOLA AIR PRESSURES MAY BE DETERMINED FROM THIS CHART.

ing air pressure in the wind belt. The coke between these limits is replaced intermittently by the succeeding coke layers.

18. The coke in the bed which is consumed to furnish the heat for melting the metal charges is replenished by the intermediate coke charges. In this way, the coke bed is maintained at the correct level to insure favorable melting conditions. To decrease the formation of carbon monoxide which lowers the temperature of the gases, the coke charges are kept as small as practical. With the ordinary sizes of foundry coke, layers less than 6 in. thick are not readily obtained. Therefore, each coke charge will contain a definite weight of dry coke which can be placed in a height of 6 in. within the cupola. This amount of coke can be determined experimentally by weighing the coke which will fill a cylinder having the same

diameter as the cupola and a height of 18 inches, and dividing by three.

19. The volume occupied by one pound of foundry coke varies with the method of manufacture, as well as the care taken in handling this fuel. If the relation of weight to volume for a specific coke cannot be found by trial, it may be assumed that as an average, one pound of foundry coke occupies 65 cu. in. The weights of the coke charges given in Table 3 for cupolas of different sizes were calculated on this basis. The coke charges are placed as level as possible over the entire area of the cupola so that the top of the coke bed will remain level during the entire melting period.

20. When large pieces of iron scrap or large bundles of steel scrap are included in the metal charges, it is desirable to have the coke charges of sufficient thickness so that combustion will be maintained for the length of time required for all of the metal in each charge to be melted before it reaches the region containing free oxygen.

THE METAL CHARGE

21. Heat from the combustion of the coke preheats, melts, and superheats the pig iron and scrap metals in the charges. The ratio of the weight of metal melted for each pound of coke is dependent upon a number of conditions among which are (1) the quality of the coke, (2) the relative proportion of the surfaces of the pieces of metal which are exposed to the hot gases, and (3) the amount of superheat required in the metal. The greater the fixed carbon content of the coke, the more heat will be produced from a given weight of this fuel. Scrap metals having relatively thin sections absorb heat more rapidly than heavy pieces of pig iron or scrap. Furthermore, the metal which is poured into castings with light sections is usually heated to higher temperatures than the metal which is used in castings with heavy sections.

22. When steel scrap is used in the charges for the cupola, some carbon is necessarily consumed in carburizing this material. Therefore, the ratio of the weights of metal to coke must be established on the basis of all of the operating conditions. The values given in Table 2 for the pounds of iron melted per pound of coke are based upon the assumption that 50 per cent of the heat produced from the combustion of the coke is used in melting and superheating the iron. The ratios which are most commonly used are

Table 3

WEIGHTS OF MATERIALS IN CUPOLA CHARGES

Dia. Inside Lining, In.	Area Inside Lining, Sq. In.	Volume 6 In. High, Cu. In.	Coke per Charge, Lb.	Limestone per Charge, Lb.	Weight of One Metal Charge				
					Ratio 7 to 1, Lb.	Ratio 8 to 1, Lb.	Ratio 9 to 1, Lb.	Ratio 10 to 1, Lb.	Ratio 11 to 1, Lb.
32	804	4824	74	15	518	592	666	740	814
36	1018	6108	94	19	648	752	846	940	1034
42	1385	8310	128	26	896	1024	1152	1280	1408
48	1810	10,860	167	33	1169	1336	1503	1670	1837
54	2290	13,740	211	42	1477	1688	1899	2110	2321
60	2827	16,962	261	52	1827	2088	2349	2610	2871
66	3421	20,526	316	63	2212	2528	2844	3160	3476
72	4072	24,432	376	75	2632	3008	3384	3760	4136
78	4778	28,668	441	88	3087	3528	3969	4410	4851
84	5542	33,252	512	102	3584	4096	4608	5120	5632
90	6362	38,172	587	117	4109	4696	5283	5870	6457

from 7 to 11 pounds of metal melted per pound of coke. The weight of one metal charge is found by multiplying the weight of one coke charge by the factor which will give the desired amount of superheat in the metal. In Table 3, the weights of one metal charge are given for cupolas of different sizes.

23. The non-metallic, non-combustible materials which accompany the cupola charges, or are produced during the melting operation, form a viscous slag within the cupola. If this slag is allowed to accumulate in sufficient quantity, it will interfere with good melting practice. Combustion of the fuel and the melting of the metal are retarded by the presence of a gummy slag which adheres to the surfaces of the pieces of the stock. Furthermore, slags which fuse at high temperatures obstruct some of the gas passages through the charges, and this condition will make uniform melting impossible. The viscosity of cupola slags can be lowered by the addition of fluxes to the charges. Limestone ($CaCO_3$) is the most important cupola flux, although fluorspar (CaF_2) and soda ash (Na_2CO_3) are also used for this purpose.

24. The most satisfactory fluxing material is calcium oxide (CaO) which is produced by the decomposition of limestone within the cupola. The calcium oxide combines with silicon dioxide (SiO_2) to form a calcium silicate slag.

$$CaO + SiO_2 \rightarrow CaSiO_3$$

This reaction requires 1.66 lb. of pure limestone, or 1.71 lb. of limestone containing 3 per cent of impurities, to unite with each pound of silicon dioxide (SiO_2) or silica.

25. The silica (SiO_2) content of the cupola charges is derived mainly from the ash of the coke, from the products of oxidation of the metal, and from the sand on the iron scrap. If it is assumed that the coke contains 10 per cent ash, and that 250 lb. of coke are required to melt 2000 lb. of metal, 25 lb. of ash will be produced in the cupola during the melting of every ton of metal. Since the ash contains approximately 50 per cent of its weight of silica, the combustion of 250 lb. of coke will produce 12.5 lb. of silicon dioxide.

26. During the melting of the metal mixtures in the cupola, silicon is oxidized to the extent of about 10 per cent of the total silicon in the metal charges. The silicon dioxide from this source collects in the cupola slag. If it is assumed that the total metal mixture contains 2.20 per cent silicon, the normal oxidation of 2000

pounds of metal will result in the formation of 9.4 pounds of silicon dioxide. When this amount is added to the weight of silicon dioxide from the coke used in melting the metal, a total of 21.9 lb. will be obtained. The weight of limestone which will be required to produce a liquid slag by combining with the silicon dioxide from these two sources alone amounts to 37.4 lb. This is equivalent to about 15 per cent of the weight of the coke used.

27. Other sources of slag are the cupola patching material and the sand on the metals which are charged into the furnace. It is necessary to apportion the limestone according to the conditions of operation for every cupola. As a rule, 20 per cent of the weight of the coke consumed in melting is a satisfactory proportion for the limestone additions. The limestone flux is distributed uniformly over each coke charge and is kept away from the lining. Since the coke can usually be placed more level in the cupola than the metal charges, the limestone can be distributed more uniformly over the coke layers.

26. Fluorspar is a very active fluxing agent for cupola slags and is often supplied with limestone in the cupola charges; as little as 5 per cent of the weight of the limestone is sufficient to increase noticeably the fluidity of the cupola slag.

27. Soda ash is also used to increase the fluidity and the dissolving action of cupola slags. Under favorable conditions, soda ash is a valuable desulphurizer of the metal. A combination of one part of soda ash and ten parts by weight of limestone is sometimes used as a cupola flux.

THE AIR SUPPLY

28. The operation of the cupola furnace requires a continuous supply of fuel and air. The volumes of air required to burn one pound of coke under different combustion conditions have been derived and are given in Table 1. Also, the method of computing the weight of one coke charge has been established, and the weights of the coke charges for cupolas of different sizes are given in Table 3. From these values, the volume of the air required for the combustion of one coke charge can be readily found. The amounts of air which will burn one coke charge under combustion condition *F* in cupolas of different sizes are given in Table 4. These values do not take into account any losses in the blast pipe or wind belt.

29. It is proposed that the rate of burning the coke and

Table 4
AIR SUPPLY AND MELTING RATE

Dia. Inside Lining, In.	Lb. Coke per Charge 6 In. High	Cu. Ft. Air to Burn One Coke Charge, Total	Cu. Ft. of Air per Min.			Melting Rate: Tons per Hour					
			To Burn One Coke Charge in 4 Min.	To Burn One Coke Charge in 5 Min.	To Burn One Coke Charge in 6 Min.	9 Lb. of Metal Melted per Lb. of Coke			8 Lb. of Metal Melted per Lb. of Coke		
						4 Min.	5 Min.	6 Min.	4 Min.	5 Min.	6 Min.
32	74	7548	1887	1509	1258	5.0	4.0	3.3	4.4	3.6	3.0
36	94	9588	2397	1917	1598	6.3	5.1	4.2	5.6	4.5	3.8
42	128	13,056	3264	2611	2176	8.6	6.9	5.8	7.7	6.1	5.1
48	167	17,034	4259	3407	2839	11.3	9.0	7.5	10.0	8.0	6.7
54	211	21,522	5381	4304	3587	14.2	11.4	9.5	12.7	10.1	8.4
60	261	26,622	6656	5324	4437	17.6	14.1	11.7	15.6	12.5	10.4
66	316	32,232	8058	6446	5372	21.3	17.1	14.2	18.9	15.2	12.6
72	376	38,352	9588	7670	6392	25.4	20.3	16.9	22.6	18.0	15.0
78	441	44,982	11,246	8996	7497	29.8	23.8	19.9	26.5	21.2	17.5
84	512	52,224	13,056	10,445	8704	34.6	27.6	23.0	30.7	24.6	20.5
90	587	59,874	14,969	11,975	9979	39.6	31.7	26.4	35.2	28.2	23.5

melting the metal in a cupola be computed on the basis of the units used in charging the solid materials. This in turn will fix the rate of supplying the air. Different rates of melting can be obtained by changing the air supply to a cupola. In Table 4, the melting rates for cupolas of different sizes are given on the basis of burning one coke charge and melting one metal charge in 4, 5, and 6 minutes.

30. One of the factors which should influence the choice of the melting rate is the cost of supplying air to the cupola. When the efficiencies of the mechanical equipment are disregarded, the horsepower for supplying air is obtained by multiplying the volume of the air in cu. ft. per min. by the pressure in oz. per sq. in. and again by the factor 0.0003. Since the pressure increases with the volume of the air delivered to a cupola, the power increases more rapidly than the melting rate. The data, shown in Table 5, apply to the operation of a 54-in. cupola.

Table 5

EFFECT OF AIR VOLUME ON COMBUSTION RATES

	Combustion Rate		
	4 Min.	5 Min.	6 Min.
Volume of Air, Cu. Ft. per Min.	5,381	4,304	3,587
Average Operating Air Pressure, Oz. per Sq. In.	20	13	9
Melting Rate, Tons per Hour	14.2	11.4	9.5
Horsepower Required	32	16	10
Horsepower per Ton per Hour	2.3	1.4	1.1

31. It has been shown that the cost of power is less for the slower melting rate; however, other conditions may offset this advantage. The requirements for molten metal from a single melting unit may make it necessary to use more rapid melting. A 72-inch cupola has been operated to melt 30 tons of iron per hour, which is equivalent to a rate of 3 minutes for burning one coke charge and melting one metal charge. The practice which is generally favored is to use a combustion rate of 5 minutes for each coke charge.

32. Any changes in the melting rate of a cupola must be accompanied by corrections in the height of the coke bed, if favorable combustion conditions are to be maintained. When the melting rate is decreased by supplying less air, the height of the coke bed is automatically lowered as a result of the forma-

tion of carbon monoxide gas. On the other hand, when the air supply is increased, the pressure in the wind belt, and hence the velocity of the gases in the coke bed, is increased. This causes the region containing free oxygen in the cupola to be raised and makes a higher coke bed necessary to avoid the oxidation of the metal charges. The only method of raising the height of the coke bed after the operation of the cupola has been started is to supply extra coke to the subsequent charges. Therefore, it is not good practice to increase the air supply without providing in advance the extra coke needed to build up the bed.

PENETRATION AND DISTRIBUTION

33. The actual conditions of the penetration and distribution of the air which is supplied to the cupola furnace are often misunderstood. Many designs of special tuyeres have been proposed for obtaining greater penetration of the air towards the center of the cupola. Since the coke bed forms an ideal baffle to the directional penetration of the air stream, there is no possibility of forcing the air in a given direction by restricted areas or by special shapes of tuyeres. It has also been assumed that air at low pressure would travel up the lining of the cupola and would not penetrate the bed coke.

34. To determine the actual distribution of the air within the coke bed of a cupola furnace, the following investigation was carried out. Twenty-eight copper tubes $\frac{1}{4}$-in. in diameter were placed in the coke bed of a 32-in. cupola with their ends at seven equidistant positions across the bed and at levels of 14, 20, 26, and 32 inches above the top of the tuyeres. These tubes extended to the outside of the cupola and were connected to water manometers. The entire coke bed containing pieces of coke averaging 3 in. in size was then built up to a height of 48 in. above the top of the tuyeres. A positive-displacement blower driven by a variable-speed motor was used to supply air to the cupola. Four rectangular tuyeres with a total inside area of 95 sq. in. were provided. With a pressure of only 4 oz. per sq. in. in the wind belt, the pressures across each level of the coke bed were nearly the same with a tendency for slightly higher pressures in the center of the cupola at the lower levels where the measurements were made.

35. Materials were then charged into the cupola on top of

the coke to increase the resistance to the flow of the air. When the pressure in the wind belt was raised to 10 oz. per sq. in., the pressures across the bed at each level were practically constant with slightly increased pressures at the center of the cupola. These measurements were made with the air and coke bed at room temperature. Under normal operation of the cupola, other conditions such as the expansion of the gases by heat and the increase in volume due to the formation of carbon monoxide gas will probably influence the distribution of the gases to some extent. However, it could reasonably be expected that the distribution of the gases across the bed of the cupola above the tuyeres when the coke is burning is fairly uniform. The construction of the coke bed is such as to favor the distribution of the air in the cupola except when careless charging or insufficient slagging causes the obstruction of the gas passages through the bed.

36. On the basis of the results obtained from the investigation described above, there is little prospect of any advantage to be gained in the distribution of the air by restricting the area of the cupola above the tuyeres or by reducing the size of the tuyere openings.

Summary

37. The data presented in this paper may be summarized as follows:

1. The reactions which occur in each of four zones in the cupola are explained.
2. The conditions resulting from the combustion of carbon are arranged in eleven groups based on the proportions of carbon dioxide and carbon monoxide in the gases. The air required to burn one pound of coke under each combustion condition is given in Table 1.
3. The weight of iron melted and superheated to each of three temperatures with one pound of coke is given in Table 2.
4. The original and operating heights of the coke bed for different air pressures have been derived and are shown in Fig. 3.
5. The method of finding the weight of coke in each charge is explained and the weights of coke charges for cupolas of different sizes are given in Table 2.
6. The factors which determine the weight of each

metal charge are discussed and the weights of metal charges for cupolas of different sizes are given in Table 2.

7. The amount of flux to be used in cupola melting is derived; as a rule, 20 per cent of the weight of the coke consumed in melting is a satisfactory proportion for the limestone additions.

8. The melting rate for any cupola is dependent upon the rate of supplying the air. It is shown that the power required to deliver air to the cupola varies with the speed of melting. A combustion rate of 5 minutes for burning one coke charge 6 inches in height is preferred. An increase in melting rate requires additional coke in the bed.

9. The results of an investigation to determine the distribution of air in a cupola indicate that the air is uniformly distributed when the pressure in the wind belt is 4 ounces and 10 ounces per square inch. Therefore, it is unnecessary to decrease the size of the tuyeres or to bosh the cupola above the tuyeres to obtain penetration of the air to the center of the cupola.

Recommended Procedure for Analysis of Defects in Brass and Bronze Sand Castings

To Non-Ferrous Division:

It is the purpose of your committee to lay out a schematic procedure for the analysis of defects commonly found in sand castings of brass or bronze. In doing so we propose, first of all, to list and define what we may call the symptoms, that is, those imperfections, usually visible, which call attention to the fact that the casting is defective. Eventually these should probably be illustrated by means of photographs or sketches.

It is intended to include all defects which originate in the foundry, some of which do not become apparent until the casting has been machined or tested.

In the following list an attempt has been made to define briefly the symptoms which enable the foundryman to recognize that there is something wrong with his casting without attempting to indicate the cause of the defect, although in some cases this may seem fairly obvious. The terminology is important and it is hoped that by criticism and suggestion we may be able to arrive at a use of terms and expressions which will be generally understood by all foundrymen. At present, round-table discussions and the like are noticeably hampered by the fact that many terms in common use do not mean the same thing to the various men taking part in the discussion.

Character of Defects

1. *Misrun.* A casting which lacks completeness due to the fact that the mold cavity has not been wholly filled with metal. There may be a smoothly rounded hole through the wall of the casting or one or more extremities may be only partially filled out.

2. *Cold Shut.* The casting appears to be cracked but on closer examination it is found that the metal has failed to join or coalesce along the line of the apparent crack. In some cases, partial coalescence leaves a line of weakness which later does crack.

3. *Shift.* A casting in which the cope and drag portions do not exactly match at the parting line.

4. *Crush.* A casting showing a deformation apparently due to displacement of the sand when the mold was closed.

5. *Variation in Wall Thickness.* A casting which at one or more points shows more or less metal than is called for in the print.

It may be uniformly too heavy, uniformly too light, or may be too thick on one side of a cored cavity, too thin on the other.

6. *Sand Wash.* The casting may have rough lumps of metal at some point on its surface or may exhibit rounded corners which should be sharply defined. At other points there will be roughly granular depressions or holes.

7. *Sand Blow.* The casting shows an unnaturally smooth depression at one or more points on its outer surface.

8. *Core Blow.* The casting shows a smooth blackened depression on an inner surface where there is a cored cavity or, often, a large gas pocket with black surface in some heavy portion of the casting above the level of the cored cavity.

9. *Scab.* A rough spot, usually on a thin-walled portion of the casting, the wall being slightly thicker than normal at this point but shot through with numerous angular holes.

10. *Burning into Sand.* Certain outer parts of the casting have a rough, sandy appearance as if the metal had penetrated freely between the sand grains, some of which are completely surrounded and enclosed in the outer wall of the casting.

11. *Burning into Cores.* Sometimes a rough, sandy inner surface, similar to the penetration of metal into green sand, but more commonly in the form of metal fins penetrating into the core and containing trapped grains of core sand.

12. *Sand Sticking in Cored Cavities,* Even when there is no apparent "burning in," castings having intricate cored passages or cavities of small dimension and relatively inaccessible, sometimes show a tightly adherent coating of sand.

13. *Superficial Imperfections.* Castings otherwise of apparently perfect quality sometimes have surface defects which may be of importance on the ground of appearance only. In other cases these apparently superficial defects are indicative of more deep seated ailments. The following are listed as typical.

A. *"Wormy" Surface.* The surface of the casting, usually in the vicinity of the gate, shows irregular depressions, shallow but elongated, similar in appearance to worm tracks. These depressions are often filled with a deposit of zinc oxide, and are sometimes accompanied by a very poor fracture, sometimes by an excellent fracture.

B. *Surface Stains.* The casting has black discolorations of varying size and shape.

C. *Tin or Lead Sweat.* The surface of the casting is more

or less covered with a thin layer of the white metal. In the case of lead the sweat often occurs in spots or lumps, sometimes of considerable thickness.

D. *Rough or Pitted Surface.* Although the casting does not show evidence of sand washing or scabbing, the surface is rough or exhibits an occasional angular pit, sometimes so deep as to leave an objectionable scar on a finish-machined surface.

14. *Solid Inclusions.* With a fracture which otherwise appears to be good, the walls of the casting contain particles or small chunks of non-metallic substance, or separate pieces of metal not coalesced with the body of the casting.

15. *Shrinkage Cracks and Cavities.* With a fracture otherwise apparently good the casting shows at one or more points a crack or cavity where the metal has pulled apart while it was still in a plastic condition. The walls of the cavity are usually tarnished to a color which varies from orange to dark brown.

16. *Weak or Discontinuous Structure.* The fracture of the casting is bad at practically all points. Commonly the structure is dendritic with minute fissures between the large crystals which are tarnished to an orange or brown color. Sometimes, with crystals of more normal size, the fracture is of a loosely granular—rather than fibrous—appearance. Other varieties of abnormal fracture may also be encountered.

17. *Sponginess.* This is a rather unsatisfactory term to describe the appearance of small but clearly discernible gas bubbles, usually segregated near the surface—but underneath the skin—of heavy sections of the casting. The cavities are approximately round and bright, free from tarnish.

18. *Subnormal Physical Properties.* The casting has no noticeable defect of any kind but fails to meet a standard test for strength, Brinell hardness, or density, when subjected to fluid pressure.

So much for the symptoms. Having observed that his casting is defective the foundryman wants to know where to look for the source of his trouble. Occasionally this is obvious; sometimes what appears to be the obvious answer is dead wrong; in other instances no explanation seems even plausible.

The first step in an attempt to systematize the connection between effect and cause, is to list in some sort of order the various operations in the manufacture of the casting where trouble may creep in. A tentative list of this kind follows:

I. Gating and layout of pattern.

II. Condition of pattern, flask, core box, etc.
III. Molding practice.
IV. Quality and condition of molding sand.
V. Quality and condition of cores, parting compound, spray and the like.
VI. Quality of the molten metal as delivered from the furnace.

This may be sub-divided as follows:

1. Quality of the various constituents in the metal mix charged into the furnace.
2. Influence of the furnace atmosphere.
3. Influence of the furnace lining and fuel (or electrodes).
4. Influence of slag, fluxes and deoxidizers.
5. Influence of the maximum temperature reached.

VII. Pouring temperature.
VIII. Pouring practice (and skimming).
IX. Cleaning practice (tumbling, sand blasting, etc.)

For a complete and exact diagnosis of foundry ills—which is admittedly hitching our wagon to a star—it is necessary for us to lay out, as well as we can, a plan by which the foundryman, having located his defect and given it a name, can at least link it up with the particular foundry operation responsible for the trouble. That, in itself, will not always indicate a remedy, but certainly the first step is to learn at what point trouble occurred; this is often difficult enough. We should be able to agree fairly well on a simple general outline of this character. As we proceed from this point in an effort to define more exactly the source of the difficulty and then to prescribe a remedy, we will undoubtedly bring up points on which disagreement will exist. This, in itself, should be useful since it will point the way to the desirability of further experimental work in controversial territory.

At this time, we have attempted merely to outline our problem and to indicate the manner in which we propose to attack it. Constructive criticism and suggestions are earnestly requested.

Respectfully submitted,

HARRY M. ST. JOHN, *Chairman,*
L. H. FAWCETT
H. J. ROAST
WM. ROMANOFF

DEOXIDATION AND DEGASIFICATION OF NON-FERROUS CASTING ALLOYS—1

Deoxidation and Degasification of Nickel Silver Alloys

By R. J. Keeley,* Philadelphia, Pa.

Abstract

The successful production of nickel silver castings, while difficult, may be satisfactorily accomplished by proper attention to details. The author cites instances where foundries were having difficulties and explains what was done to correct them. Sufficiently high pouring temperatures, proper deoxidation and correct feeding are necessary requisites to the production of consistently sound castings. The author outlines correct deoxidation procedures for nickel silver alloys of several types and for various uses.

1. The successful production of consistently sound castings in nickel silver alloys is not easily attained and requires a proper understanding of their characteristics on the part of the foundryman.

2. There are, of course, a large number of nickel silver alloys, of quite widely varying composition, in commercial production. For convenience, however, they might be defined as red brass and yellow brass mixtures containing a sufficient amount of nickel to yield the color and degree of corrosion resistance desired.

3. The nickel silvers owe their importance principally to their pleasing white color, although their durability, moderate strength and corrosion resistance, and availability are also frequently factors in their selection for a given application.

4. The two types of defects most frequently encountered, which may be attributed usually (but not always) to faulty melting practice, are porosity and a tendency for dross inclusions. Nickel alloys are susceptible to gas absorption particularly when melted under reducing conditions, the presence of hydrogen probably being particularly objectionable, and porosity may result due to this tendency. Dross inclusions may be connected with the higher temperatures involved, oxidation of zinc and other low melt-

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* Ajax Metal Co.

Note: This paper was presented at the Third Annual Conference on Deoxidation and Degasification of Non-Ferrous Casting Alloys held at the 1935 A.F.A. Convention in Toronto, Canada.

ing constituents possibly proceeding at a more rapid rate than in the lower melting brasses and bronzes. Dross inclusions may also, in some cases, be due to the failure to pour the castings at a sufficiently high temperature.

5. Due consideration of the underlying principles of degasification and deoxidation is as necessary in handling the nickel silvers as in other non-ferrous foundry mixtures. It is not the intention of this paper to discuss this subject in all its phases nor is it possible or desirable to discuss the wide varieties of so-called "deoxidizers and degasifiers" commercially available. It is rather planned to describe some of the difficulties encountered in the foundry and discuss precautions to prevent their occurrence or the steps necessary to remedy the situation. It is hoped that these brief notes will serve to stimulate interest and initiate further discussion of this group of alloys.

Melting and Pouring Temperatures

6. Frequently, difficulties in obtaining pressure tight castings are due to the failure to realize the necessity of pouring nickel silver at a suitably higher temperature than the lower melting bronze mixtures.

7. One instance (Example No. 1) might be cited here of a jobbing foundry making pressure castings in an alloy containing:

65 per cent Copper
20 per cent Nickel
4 per cent Tin
6 per cent Zinc
5 per cent Lead

Difficulty was being experienced in obtaining hydraulically tight castings. The melting practice appeared satisfactory, the melt being deoxidized with 0.10 per cent manganese shortly before removing the crucible and 0.06 per cent magnesium, just before pouring. Melting was accomplished in an oil-fired, crucible, pit furnace, and the melt was poured directly from the melting crucible.

8. The metal was poured at 2350 degrees Fahr., a temperature which is too low for this mixture when cast in moderate to light sections, and the appearance of the metal during casting confirmed this. It was decided to superheat the metal to 2500 degrees Fahr. This not only insured that the castings would be poured at a sufficiently high temperature but it was felt that the superheat and consequent increased volatilization of zinc would

have a beneficial cleansing effect assisting in the removal of reducing gases from the melt.

9. The procedure outlined above accomplished the desired results.

UNSOUNDNESS DUE TO UNSUITABLE FUEL

10. In some instances, difficulties have been traced to the use of coke of too high sulphur content. This may be particularly objectionable where the melting equipment is inefficient and the melting time, and consequently the period of exposure to the melting atmosphere, is excessive.

11. One foundry (Example No. 2) handling the following hardware alloy: 62.5 per cent copper, 5 per cent lead, 3 per cent tin, 10 per cent zinc, 19 per cent nickel, 0.5 per cent aluminum, experienced unsound castings, the porosity being in the form of sub-surface gas holes. No noticeable irregularities in melting and molding practice could be detected. Castings from the same lot of ingot were made in a nearby foundry having identical melting equipment, and were satisfactory.

12. A comparison was then made of the fuel, analyses of the coke yielding the following:

Porous castings ....1.19 per cent sulphur in coke
Satisfactory castings ....0.71 per cent sulphur in coke

13. The change to a lower sulphur coke eliminated the trouble at its source and castings subsequently made were free of sub-surface gas holes.

THE EFFECT OF ALUMINUM

14. A number of foundries (Example No. 3) cast typewriter parts in a nickel silver containing about 23 per cent nickel, 13 per cent zinc, 3 per cent aluminum, remainder copper. For this particular application, 3 per cent aluminum may be tolerated since the sections are uniform. Where non-uniform sections exist, this alloy requires excessive care in providing ample metal to avoid shrinkage difficulties. The reduction of aluminum from 3 to 0.5 per cent in this alloy greatly diminishes sensitivity to deficiencies in feeding.

15. It should be emphasized, however, that aluminum is a deleterious element in nickel silver casting alloys which must be pressure tight, and should be absent in such cases. The harmful

effect of aluminum is no doubt connected with the film forming tendencies of aluminum oxide.

THE EFFECT OF SILICON AS A DEOXIDIZER

16. For nickel silvers containing less than 2.50 per cent lead, silicon may frequently be found to be a useful addition. In one instance (Example No. 4), difficulties in the form of "leakers" were being encountered in an alloy containing 25 per cent nickel, 2 per cent lead, 1 per cent tin, 10 per cent zinc, remainder copper. On observing the metal in the molten state, it appeared to be sluggish and swelling of the sprues indicated trouble with excessive gas absorption. Successive additions of silicon were made, and the use of 0.25 per cent silicon, added as silicon-copper, was found to eliminate the "leakers." However, it was found necessary, on the addition of silicon, to make more generous provisions for feeding the castings.

DEOXIDATION PRACTICE: CASTING ALLOYS VS. WROUGHT ALLOYS

17. It might be useful at this stage to point out that the deoxidation practice which yields good pressure castings may be quite unsuited to processing of nickel silver for subsequent rolling and forming operations. Silicon, aluminum and magnesium are undesirable impurities (the maximum permissible amount varying with the element) in rolling mill alloys; the oxides of these metals interfere with the rolling operations and cause defective sheet. The general practice, therefore, is to add about 0.05 per cent manganese a few minutes before pouring into chill molds. Little difficulty is experienced with the high zinc alloys which are less sensitive to gas absorption than the low zinc alloys.

SUMMARY

18. The following general points may be helpful in the production of nickel silver:

a. Pour at a sufficiently high temperature. The proper pouring temperature will vary with the composition and requires some experimentation to ascertain the requirements in this direction.

b. For sand castings containing more than 3 per cent lead, deoxidize with:

0.10 per cent manganese (as 30 per cent manganese-

copper), added a few minutes before drawing the crucible followed by

0.05 per cent magnesium (as stick magnesium), just before pouring.

c. For sand castings containing below 3 per cent of lead, deoxidize with up to 0.25 per cent silicon (as 10 per cent silicon-copper).

d. Aluminum should be excluded from all nickel silver castings which must be pressure tight. Where pressure tightness is not involved and the sections are uniform the addition of 0.5 per cent aluminum may be recommended for some purposes and in light sections, such as typewriter parts, up to 3 per cent has been successfully used. Where non-uniformity of section exists, the aluminum content should be held as low as possible.

e. The presence of either silicon or aluminum requires more generous provision for feeding liquid metal to the castings.

f. The presence of silicon, magnesium or aluminum is objectionable in rolling mill alloys. The usual practice is to add 0.05 per cent manganese-copper a few minutes before pouring.

DISCUSSION

T. E. KIHLGREN[1] (*Submitted in Written Form*): This paper deals with a group of alloys on the casting of which the information in the literature is none too complete, despite the fact that they have been in commercial production for many years.

The nickel silver casting alloys may contain up to 30 per cent nickel and 5 to 25 per cent of zinc and are frequently modified with up to 4 per cent of tin and/or up to 5, and occasionally 10 per cent of lead, particularly where the castings must be hydraulically tight. With such a wide range of compositions, the development of the optimum foundry procedure, including deoxidation technique, requires some experimentation on the part of the individual foundryman to meet the requirements set by his own melting conditions and alloy composition.

The author mentions that the major difficulties encountered in the production of nickel silver can be ascribed to porosity due to gas absorption during melting and consequent liberation on solidification. Defective nickel silver castings, however, frequently result from the use of too low a pouring temperature or incorrect molding procedure, and while we do not wish to imply that observance of correct melting and deoxidation procedure is not important, we should like to emphasize that such precautions may

[1] International Nickel Co., Inc., Bayonne, N. J.

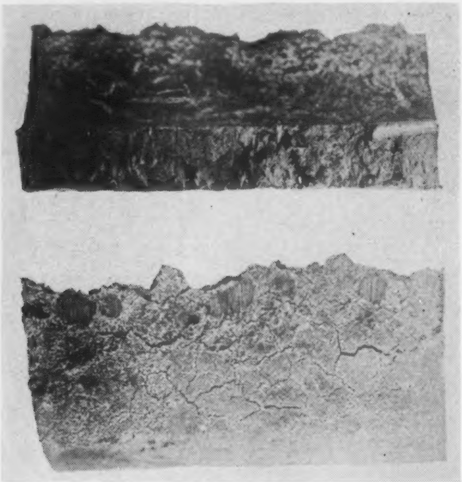

FIG. 1—FRACTURED BUSHING CASTING SHOWING EFFECT OF TREATING THE ALLOY WITH 0.30 PER CENT SILICON.

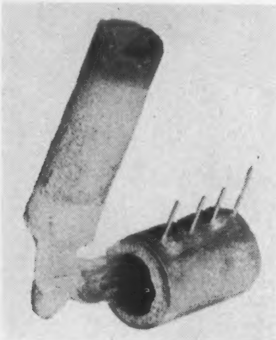

FIG. 2—HYDRAULIC AND FRACTURE TEST CASTING.

be nullified by failure to realize the need for more generous provisions for feeding nickel silver castings than are necessary for red brass, and to pour the castings at a sufficiently high temperature.

In his summary the author indicates silicon to be undesirable as a deoxidizer for nickel silver castings containing more than 3 per cent of lead, which must be hydraulically tight, a statement with which we find ourselves in complete agreement, and a few supplementary observations in this direction may be useful.

The deleterious effect of silicon on the "Federal Specification WWP 541" alloy of the type composition 20 per cent nickel, 4 per cent tin, 6 per

cent zinc, 5 per cent lead, balance copper has been described previously.* Fig. 1 shows a photograph of a fractured bushing cast in this alloy, using the casting of the type shown in Fig. 2. This illustrates the detrimental effect of 0.30 per cent of silicon. Fractures of castings in the above alloy treated with 0.10 per cent or more of silicon are invariably coarse grained, with columnar crystals, and frequently show evidence of hot cracking in the form of pale yellow discoloration of the crystal faces near the surface, and sometimes extending across the fracture. The surface network is also characteristic of castings containing excessive amounts of silicon and seems to be a focal point for hot cracking. Bushings treated with 0.10 per cent or more of silicon generally leak when subjected to hydraulic pressure. In no instance have leakers been encountered in silicon free melts cast in the same alloy, when deoxidized with 0.10 per cent manganese + 0.05 per cent magnesium + 0.02 per cent phosphorus, and the fractures have been fine grained and free of shrinks.

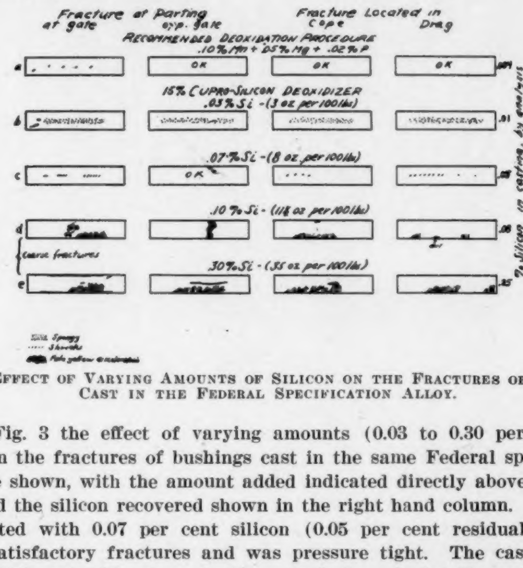

FIG. 3—EFFECT OF VARYING AMOUNTS OF SILICON ON THE FRACTURES OF BUSHINGS CAST IN THE FEDERAL SPECIFICATION ALLOY.

In Fig. 3 the effect of varying amounts (0.03 to 0.30 per cent) of silicon on the fractures of bushings cast in the same Federal specification alloy are shown, with the amount added indicated directly above the fractures and the silicon recovered shown in the right hand column. The casting treated with 0.07 per cent silicon (0.05 per cent residual) showed rather satisfactory fractures and was pressure tight. The castings containing 0.08 and 0.25 per cent silicon, leaked on hydraulic tests, showed coarsely crystalline fractures and the surface network effect was pronounced in the latter, and noticeable in the former. In view of the fact that silicon will accumulate with remelting, build-up of silicon to an undesirably high level may well occur in actual foundry practice, if it is used for deoxidation of the melts.

It may, however, be noted that, with the possibility of silicon contamination occurring, the harmful effects of such inadvertent silicon additions can be lessened by using cores which collapse readily to prevent stressing

* KIHLGREN, T. E., *"Foundry Production of Nickel Silver,"* METALS AND ALLOYS, vol. 6, nos. 6 and 7, June-July, 1935.

the metal contracting about the core (and so reduce the danger of "hot tears"), and also by making sure that the castings are generously fed.

While agreeing with the author on the undesirability of silicon in alloys containing more than 3 per cent of lead, we question the advisability of using up to 0.25 per cent of silicon on alloys containing less than 3 per cent of lead, as he recommends.

Fig. 4 shows the fracture of a bushing cast in the Federal specification alloy, with 2.5 instead of 5 per cent of lead, and deoxidized with 0.25 per cent of silicon. The coarsening effect of silicon is quite apparent, though not as pronounced as in the 5 per cent lead alloy. The fracture gave some evidence of hot cracking. This casting leaked slightly under hydraulic tests while the Mn-Mg-P deoxidized alloy, cast under the same conditions, was tight up to 1000 lb. per sq. in. hydraulic pressure.

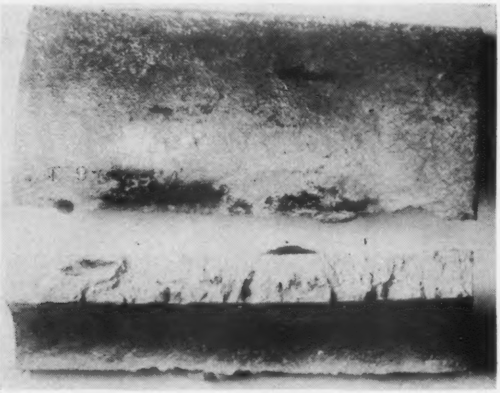

FIG. 4—FRACTURE OF A BUSHING CAST IN THE FEDERAL SPECIFICATION ALLOY WITH 2.5 PER CENT LEAD INSTEAD OF 5.0 PER CENT.

While smaller amounts may be tolerable, 0.25 per cent silicon seems dangerously high, even at 2.5 per cent lead, and our experience indicates that it should preferably be kept as low as possible.

Incidentally, it might be mentioned that the 2.5 per cent lead alloy appears to require more generous provision for feeding than does the 5 per cent lead alloy, in order to obtain sound castings.

In the author's example 2, he attributes the defective castings to the use of too high sulphur content coke. However, the difference in sulphur content of the coke used by the two foundries mentioned seems rather small and we should be inclined to question whether it is sufficient to account for the difference in the quality of castings produced in the two foundries. We have obtained tensile test castings in this type of alloy (without the aluminum), to which 0.02 per cent of sulphur has been deliberately added, which gave an excellent combination of strength and ductility.

Is it not possible that the defective castings may have been due to the

use of improper sand, of too low permeability or too high moisture content, or insufficiently vented molds? We should also like to ask the author whether 0.5 per cent of aluminum is a desirable addition to leaded alloys of this type.

In the fourth example cited, we should like to inquire whether, for pressure work, a higher lead content alloy of the type indicated in example 1 deoxidized with manganese + magnesium might not be preferable, and be less sensitive to feeding difficulties.

SAM TOUR[2]: I wish to briefly call attention to one point made in Example No. 4. The statement is made that on increasing the amount of silicon to accomplish this deoxidation or degasification, the shrinkage increased considerably and it was necessary to modify the molding practice and add risers at vital points. It is so often the case that we ascribe results to the addition of some one thing rather than to the elimination of something else. In describing this particular problem, Mr. Keeley makes the statement that on observing the metal in the molten state it appeared to be sluggish and the sprues swelled on cooling. If the sprues swelled on cooling, obviously the metal was gassed. With a gassed metal, there is normally much less need for risers than if the metal is not gassed. If his addition of silicon degassed the metal, then the fact that the metal was degassed made it shrink more and made it necessary to have larger risers. Anything else added that would degas the metal would have the same effect. In other words, I want to point out that the addition of silicon alone, *per se*, should not and I do not believe does increase the shrinkage of this alloy. If it degasses the metal, then the metal must be treated as a degassed metal, no matter what it was degassed with and, of course, it is necessary to use gates and risers for a degassed metal which will shrink normally. Silicon itself in the percentages referred to in this paper should certainly not cause an increase in shrinkage. Any degasifier would have accomplished the same effect.

DR. G. H. CLAMER[3]: Mr. Kihlgren has referred to the addition of sulphur to nickel containing alloys. Was the sulphur added as such or did the sulphur get into the metal in the form of SO_2? In the cases referred to by Mr. Keeley, the sulphur contamination resulted through contact with furnace gas containing SO_2.

Mr. Saeger of the Bureau of Standards last year presented the A.F.A. exchange paper before the International Foundry Congress. He described the effect of adding different impurities to the 85-5-5-5 alloy; among these impurities was sulphur. In the discussion of his paper, it was pointed out that there may be a difference in behavior due to the form in which sulphur was added. Attention was called to the fact that sulphur is usually picked up from SO_2 in the fuel gases.

This discussion raised a sufficiently important controversial question to authorize the repetition of the experiments by adding the same sulphur content in the metal in the form of SO_2. In the case of 85-5-5-5 alloy it was found that there was really no difference in characteristics whether sulphur was added in stick form or SO_2. I am raising the question now

[2] Lucius Pitkin, Inc., New York, N. Y.
[3] Ajax Metal Co., Philadelphia, Pa.

to offer the suggestion that we probably cannot draw the same conclusion with respect to nickel alloys.

MR. KIHLGREN: In the incident cited, the sulphur was added as a nickel-sulphur alloy.

W. ROMANOFF[4]: In Example No. 2, Mr. Keeley speaks of the detrimental effect of high sulphur coke. If the sulphur was in the coke in the form of a sulphide, for instance iron sulphide or some other inorganic form, it would naturally be eliminated in the form of an ash.

If it were in the form of an organic compound and given off as a sulphur dioxide gas, it would hardly be harmful, as most nickel silver is melted under a cover of some kind, such as glass, etc., and this would most likely prevent the sulphur from being introduced into the metal.

In Example No. 3, as long as the alloy does not contain lead, why not strengthen it by adding a little silicon instead of aluminum. This would avoid the possibility of contaminating nickel silver heats that are to be used in the making of pressure castings with aluminum.

MEMBER: Which of the various methods of deoxidation gives the greatest fluidity?

MR. KEELEY: It is my opinion on that question that aluminum would perhaps produce the greatest fluidity.

N. F. TISDALE[5]: I was sorry to notice we did not hear anything about deoxidizers of the boron family. It just so happens that during this spring our company developed a manganese boride for deoxidizing nickel silver.

In listening to the paper, one point which I thought should be brought out more plainly was the question of how these gases were formed and that again goes back to the melting. It seems to me that when you speak of degasification you cover a multitude of sins. For instance, does the author mean carbon dioxide, carbon monoxide, hydrogen, nitrogen, SO_2, or what? In the general types of degasification or deoxidation, there is one deoxidizer or one degasifier that will take care of one thing and another type will take care of something else. I wonder if we have not overlooked the fact in talking of degasification that it starts in melting and why not give some consideration to your type of melting? I mean by that your furnaces and some control of the atmospheric conditions. Our particular deoxidizer does not work satisfactorily on metal which has CO present resulting from melting in a reducing atmosphere. If some person happened to be using our deoxidizer and got poor results they might blame it on the deoxidizer or degasifier. On the other hand, some other person making the same material and omitting this condition would think we had a wonderful deoxidizer.

MR. KEELEY: In Example No. 2, Mr. Kihlgren raises the question as to whether the difference in sulphur content of the two grades of coke accounts for the varying results obtained in the two foundries. In answer to this question, I might say that this has been the subject of considerable discussion and we are conducting further experiments with the use of a by-product coke of a much lower sulphur content with the view of obtain-

[4] Technical Supt., H. Kramer and Co., Chicago, Ill.
[5] Molybdenum Corporation of America, Pittsburgh, Pa.

ing more convincing comparative data on this point. The results of these experiments are not yet available but will probably be finished in the near future.

In regard to the addition of 0.5 per cent aluminum to this alloy, it has been our experience that most foundries use aluminum for this type of alloy when making castings that are not subject to pressure requirements.

In Example No. 4, as to the question of lead content, this alloy was produced in ingot form to meet a specific formula and we were not permitted to deviate from the formula shown. Possibly a modification of this alloy would prove desirable.

Regarding Mr. Tour's comments covering Example No. 4, in which he voices his opinion that the shrinkage was due to the fact that the metal was degassed and not caused by the presence of excess silicon, it appeared to the observers that the shrinkage increased with gradual increase of silicon content. This would seem to prove that the shrinkage was not due to degassification alone, otherwise, the shrinkage would not have progressively increased.

There is another point that might be brought out here and that is that the casting in question was considered to be of faulty design. It was very difficult to feed since it was of varied cross-section, having thick sections adjoining thin sections and the shrinkage occurred at the junction point between such sections. It was therefore very diffiult to attach risers at the proper points.

In answer to Mr. Romanoff's question regarding Example No. 3, as to why aluminum was used instead of silicon for deoxidizing purposes, this alloy was orginally developed for typewriter parts, having small cross-sections compared with their lengths. This necessitated extreme fluidity combined with high tensile strength. These properties were obtained by the addition of aluminum. As stated, this alloy is not intended for pressure work and if used for such purpose, the addition of silicon would be preferred.

In Example No. 4, Mr. Romanoff points out, the addition of silicon may increase the hardness of the alloy, but in this instance it apparently did not effect the machinability of the metal.

Mr. Tisdale brings up a very proper question in regard to what is meant to degassification. It is our understanding that degassification means removing any gas that is dissolved in the molten metal and which is liberated on cooling and trapped therein upon solidification of the metal. The gas we refer to in general is carbon monoxide.

In reply to the question as to why silicon cannot be used in alloys containing over 3 per cent lead, it is the concensus of opinion that silicon reacts with lead to form lead silicide. However debatable this theory may be it is nevertheless a fact that it is common practice to use silicon as a deoxidizer for nickel silver alloys containing not over 3 per cent of lead. It is probable in such low lead alloys that lead silicide is formed, but the amount is so small that it does not produce hard spots in the metal.

DEOXIDATION AND DEGASIFICATION OF NON-FERROUS CASTING ALLOYS—2

The "Modifying" Phenomenon and Its Probable Relation to Properties of Non-Ferrous Alloys

By C. H. Lorig* and R. W. Dayton*, Columbus, O.

Abstract

This paper deals with the application of the "silicate-slime" or "slag cloud" hypothesis, developed to explain graphite formation in cast iron, to non-ferrous alloys. The authors review the work of various investigators in both the ferrous and non-ferrous fields and explain how the theories mentioned might be applied to non-ferrous cast alloys to explain why such alloys which are sound, reasonably free from contaminating metallic elements and of good manufacture sometimes possess irregular, if not totally dissimilar properties.

1. It seems unusual that a non-ferrous cast alloy of given composition which is sound, reasonably free from contaminating metallic elements and of good manufacture should possess irregular if not totally dissimilar properties. However, such inconsistencies do occur and have been much investigated and discussed. The lack in regularity of properties has been attributed to variations in structure and grain refinement, to inadequate feeding of the casting and thus to minute or submicroscopic porosity, to differences in melting and pouring technique and to other causes.

2. Though these all leave their influence on properties and can account for the observed variations, further analyses lead to the somewhat speculative conclusion that these might not be the basic causes, but rather that they accompany more fundamental phenomena.

3. A hint of explanation for the pronounced irregularities in properties of non-ferrous cast alloys is contained in references to the effect of inclusions in ferrous alloys. The effect of inclusions in steel is clearly shown in the "Grain Size Symposium" of the American Society for Metals, 1935. A more recent idea[1] in con-

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NOTE: This paper was presented at the Third Conference on Deoxidation and Degasification of Non-Ferrous Casting Alloys at the 1935 Convention of A.F.A. in Toronto, Canada.

[1] von Keil, O., Mitsche, R., Legat, A. and Trenkler, M.: *"Der Einfluss Nicht-Metallischer Keime auf die Graphitausbildung in Gusseisen. Vererbungserscheinungen in Gusseisen und Deren Ursachen,"* Archiv. für das Eisenhüttenwesen, vol. 7, April, 1934, pp. 579-584.

nection with the solidification of cast iron is that a silicate slime has a large effect on the graphite size and on the "heredity." Such references make it easy to imagine that the same principles regarding inclusions may apply with equal preciseness in non-ferrous practice.

4. In a correlated abstract on "Heredity in Cast Iron," Gillett[2] states that, "quite recently, v. Keil and co-workers put forth the interesting idea that neither graphite nor total oxygen govern whether the cast iron will show coarse, primary graphite, or fine nodular graphite resulting from break up of cementite, but rather the presence or absence of a 'ferrous silicate slime' a submicroscopic suspension of finely divided silicate slag particles." He further states, "that submicroscopic particles may exist in solid or liquid metal and vastly affect their performance is not difficult for present-day metallurgists to believe, in view of what is known about precipitation-hardening alloys, and about the effect of the addition of aluminum, titanium, vanadium, etc. to steel for producing controlled grain size and resistance to aging."

EFFECT OF NUCLEI

5. The "silicate slime" or "slag-cloud" hypothesis states that minute inclusions of some types act as nuclei for crystallization. Thus far the nature and number of non-metallic inclusions which function as nuclei are not accurately known. With a fairly large number of nuclei-forming inclusions present, the metal will not undercool and hence will freeze according to the stable (normal) system. By either diminishing the quantity of these inclusions or by rendering them innocuous as nuclei, the metal will undercool and will solidify according to the metastable (supercooled) system. This may lead to fine-grained and to modified structures. It is the capacity for supercooling before solidification commences which seems to account for the metal's vast differences in behavior and properties.

6. It is usually agreed that the final structure is influenced greatly by the number of nuclei present when solidification begins. Pessl[3] summarizes the two sources for nuclei as follows: first, intrinsic nuclei, the remnants of crystals which are small masses in which the atoms retain the crystalline lattice in the liquid; and

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[2] Gillett, H. W., *"'Heredity' in Cast Iron,"* METALS AND ALLOYS, vol. 5, September 1934, pp. 184-190.

[3] Pessl, H., *"Superheat Destroys Crystal Nuclei,"* METAL PROGRESS, vol. 27, May 1935, pp. 61-62.

second, solid foreign bodies either of metallic or non-metallic particles. It is conceivable that tiny gas bubbles present in the metal when the metal freezes may also act as nuclei and therefore become involved in crystallization of the metal.

7. The assumption that tiny gas bubbles and metallic particles may function as centers for crystallization merely enlarges on the "slag-cloud" hypothesis.

8. In view of these generally accepted ideas regarding the effects of inclusions in ferrous alloys, it naturally follows that similar reasoning may be equally applicable to systems of non-ferrous alloys.

COMMENTS ON HYPOTHESIS

9. As early as 1929, Norbury[4] observed the analogous appearance of the fine and coarse graphite structures in gray cast irons and the fine and coarse structures obtained in modified and normal aluminum-silicon alloys. He suggested that from analogy with cast iron, the action of the modifiers in aluminum-silicon alloys "may consist in fluxing and removing from the melt particles—such as oxides—which act as nuclei." It had been recognized earlier[5] that the aluminum-silicon alloys may freeze according to a supercooled or to a normal system depending on whether the alloys were or were not modified.

10. Mitsche[6] carried the analogy further and discussed the modification of the normal aluminum-silicon alloys from the point of view of the "slag-cloud" hypothesis. He reasoned that the modifying action, brought about by adding metals or salts or by chill casting the alloys, altered the quantity or the effect of the non-metallic inclusions thus increasing the undercooling capacity of the alloys. The resultant effect was the formation of fine-grained, granular eutectic instead of coarse, acicular eutectic on solidifying the alloys.

11. Other systems of alloys, as Gwyer and Phillips[5] enumerated, are capable of modification by additions of proper modifiers. Thus they have listed certain aluminum-nickel and the aluminum-copper alloys as being capable of modification by additions

[4] Norbury, A. L., *"Constitution Diagrams for Cast Irons and Quenched Steels,"* JOURNAL, Iron and Steel Institute, vol. 119, 1929, pp. 443-471.
[5] Gwyer, A. G. C., and Phillips, H. W. L., *"The Constitution and Structure of the Commercial Aluminum-Silicon Alloys,"* JOURNAL, Institute of Metals, vol. 36, 1926, pp. 283-324.
[6] Mitsche, R., *"The Flotation of Non-Metallic Inclusions in Molten Metals,"* CARNEGIE SCHOLARSHIP MEMOIRS, Iron and Steel Institute, vol. 23, 1934, pp. 65-105.

of metallic sodium or sodium fluoride, certain aluminum-manganese alloys by means of sodium fluoride, some lead-antimony alloys and the antimony-copper alloys by means of metallic aluminum and certain iron-aluminum alloys by means of sodium hydroxide.

12. Unfortunately the "slag-cloud" hypothesis, as well as older hypotheses used for explaining the modification of alloys, are limited in proof by the absence of suitable methods for revealing the mechanism of the action. The same lack of proof would exist were the hypotheses applied to non-ferrous alloys in general.

13. Since the "slag-cloud" hypothesis appears generally applicable to all alloy systems, it seems logical to postulate the application of this hypothesis to the more common non-ferrous foundry alloys, and thus to attempt to explain their irregularities in properties in this way.

Effect of Slag Cloud on Crystallization

14. According to the reasoning contained in the "slag-cloud" hypothesis, species of submicroscopic entities existing in the liquid metal may or may not function as nuclear centers for controlling the crystallization and hence the structure and properties of the alloy. When the species are such as to cause them to function as efficient nuclear centers permitting normal crystallization, on freezing their presence may be accompanied either by coarsening of the grain, coring, the formation of large dendrites and the development of certain average properties in the alloy when the number of nuclear centers is not excessive, or by grain refinement, less segregation and the development of other average properties in the alloy when the number of nuclear centers is excessive. On the other hand, when the species are such as not to influence crystallization, undercooling may be permitted in the metal, the latter being accompanied by grain refinement, decreased segregation, and different average properties.

15. The existence of various species of inclusions, of gas bubbles and of minute particles of metal or metallic compounds in non-ferrous alloys is often revealed on examination. Even when not detected at high magnifications because of their size, their presence is not entirely a matter for conjecture, but is revealed by such physical evidence as peculiarities in structure, differences in densities, or changes in properties caused by precipitation hardening.

16. In their function as nuclear centers, these myriads of

tiny gaseous or solid particles are of different degrees of effectiveness, some causing the metal to solidify according to the normal system while others, being innocuous, permit the metal to undercool. The characteristics which distinguish the entities which function as nuclear centers from those which do not, are not well established. In no small way, however, are these characteristics governed by such factors as the size and concentration of the entities, their solubility in the liquid and freezing metal, their refractoriness, their species, the presence of other species, the ease with which the entities are destroyed or altered in composition, the nature and composition of the metal in which the entities are dispersed and the rate of solidification of the metal.

17. Neither large particles nor those of atomic dimensions will act, conceivably, as effective centers for crystallization. There must, therefore exist some critical particle size from which any departure leads to diminishing effects. Various practices during melting or during handling of the metal before pouring may further alter the effectiveness of given particles by permitting them to volatilize, hence to change their concentration, or by causing them to coalesce, to be reduced, or to combine with other particles thus not only changing their size and concentration but their composition as well.

SUPERHEATING AND DEOXIDATION

18. Two practices in the foundry, namely superheating and deoxidation, may be looked upon as especially productive in changing the character of submicroscopic entities that constitute the "slag-cloud." Superheating, for example, may cause the cloud to volatilize or to coalesce and therefore separate from the bath either by evolution or by flotation. It may also destroy the cloud by shifting its mass equilibrium. While the purposes of adding deoxidizers and degasifiers to alloys are quite generally understood, their ability to destroy or create species of suspended slag-clouds are less generally appreciated. The resultant effect of superheating and of adding certain deoxidizers and degasifiers to alloys may lead to the destruction of crystal centers or to the creation of new centers, to the spontaneous crystallization of the alloys in the supercooled state or to normal crystallization, and finally to wide variations in properties of a given alloy.

19. In as much as cast alloys are used in the form in which

they crystallize, there is little or no chance for the structure to be rearranged either by working or by heat treatment. They are therefore, particularly susceptible to the above mentioned modifying action when it occurs. The few isolated examples of non-ferrous alloys deliberately modified either with modifiers, by superheating or by chill casting show the vast possibilities of utilizing the modifying action to good advantage. Furthermore they suggest that other alloys may unknowingly exist in some state of modification which would account for variations in structure, strength and ductility.

20. The "slag-cloud" species can either be different or can respond differently in various alloys. Therefore, for physical and chemical reasons, each alloy will respond to individual modifiers or modifying practices in its own way, thus leaving the problem of modification a matter of choosing correctly the proper set of conditions. For the above reason, after taking due account of the species of "slag-cloud" in the liquid alloy, the selection of the proper modifiers or modifying conditions to obtain modification is important.

MODIFIERS

21. Among the modifiers are those metals and salts which are strongly deoxidizing. Aluminum, titanium and vanadium in steels, magnesium, titanium, calcium and silicon in cast iron, and sodium and salts of sodium in aluminum alloys are examples of strong deoxidizers which function well as modifiers. It is not axiomatic, however, that all strong deoxidizers are good modifiers.

22. While it is unlikely that modification of brasses and bronzes had been considered, there is every reason to believe that the principles of modification are of apparently general application to these alloys as well. A recent reference by Weimer[7] indicated that certain wrought brasses and bronzes are improved by sodium additions. These may be cases where the improvement follows the removal of deleterious inclusions and gas cavities. However, the mere fact that greater uniformity in structure and freedom from segregation occurred, suggested an action similar to the modification of aluminum-silicon alloys. Other common additions may function with a greater or lesser degree of success.

23. The uses of small additions of iron, manganese, molyb-

[7] Weimer, B. A., *"Sodium-Zinc Alloy,"* THE DU PONT MAGAZINE, vol. 29, April 1935, pp. 18-19, 24.

denum, tungsten and other sparsely soluble metals in copper alloys to inhibit grain growth are likely examples of the manifestation of the same modifying phenomenon. In these instances, the precipitation of masses of tiny metallic inclusions in the freezing metal may cause innumerable new crystals to grow, with the metallic inclusions as centers, and thus to bring about an exceedingly important grain refinement.

24. The various studies of the modification of aluminum-silicon alloys disclosed that optimum conditions exist which, if not approached or if exceeded, cause either insufficient modification or else a reversion of the alloys to their normal state. The modified state of alloys is, therefore, an unstable one and precautions must be taken in realizing its full benefit. Such practices as the introduction of the modifiers at too early a stage or in too great amounts, the superheating or the stirring of the metal after the modifiers are added, the stirring of the metal after superheating, the superheating of the metal in deleterious atmospheres, the remelting of modified alloys, the exposure of the modified alloy to certain atmospheres and the cooling of the modified alloy too slowly may easily nullify the modifying effects allowing the metal to solidify according to the normal (stable) system. Hereditary tendencies in modified alloys are known but whether they can be expected to remain after repeated melting will be determined by the degree of unstableness of the alloys.

25. It is quite evident that the problem of modifying non-ferrous alloys, particularly the more common foundry alloys, is very involved. Whether we can hope to explain all the phenomena relating to irregularities in properties of non-ferrous alloys by the "slag-cloud" hypothesis remains to be proved. The hypothesis is offered as a working tool for guiding one toward obtaining better and more uniform properties in cast alloys with the hope that eventually a theory will evolve whose application will immediately lead to improved properties in cast alloys.

DISCUSSION

O. W. ELLIS:[1] The slag cloud hypothesis, which has been presented so ably in this paper by Messrs. Lorig and Dayton, is worthy of our attention, though at the moment much experimental work is required to convince most people of its value.

There are one or two points in connection with the hypothesis, that have not been mentioned by Dr. Lorig but that I would like to emphasize. According to the slag cloud hypothesis, one must visualize a metal or an alloy in the molten state, throughout which a cloud of tiny particles of non-metallic substances (sonims) is distributed. I take it from the hypothesis that if the temperature of the molten metal or alloy be sufficiently raised, this cloud will, under certain circumstances, partly or completely disappear; in other words, as the temperature of the molten metal or alloy is raised, the particles forming the cloud will enter more or less completely into solution in the melt.

Now, I believe we can presume that under certain circumstances of cooling the particles can either be caused to reappear (come out of solution) in the melt, or be prevented from reappearing (stay in solution) in the melt. If the rate of cooling is sufficiently fast and the particles are of a particular type, once having gone into solution they will remain in solution. The same type of particle, if cooling of the *molten* metal or alloy is sufficiently slow, will come out of solution. It seems, therefore, that much work needs to be done on the effects upon slag clouds of varying the rates of cooling of metals and alloys while in the liquid state. For instance, one experiment might consist in heating a molten alloy to a high temperature, allowing part of it to cool slowly to a lower temperature and another part to cool rapidly to the same temperature, then pouring both portions of the alloy into suitable molds at this lower pouring temperature, subsequently comparing the structures of the castings produced.

There are considerable differences of opinion as to the effect of superheating upon the characteristics of cast iron, for example. We at the Foundation have been interested in white cast iron and determined to see to what extent the slag cloud hypothesis could be made to explain the results of certain experiments. We poured what we expected to be a white iron into a sand mold at 1300 degrees Cent. (2372 degrees Fahr.) and obtained a gray casting. Metal poured at 1400 degrees Cent. (1552 degrees Fahr.) gave white castings, and metal poured at 1500 degrees Cent. (2732 degrees Fahr.) also gave white castings. When we allowed material which had been superheated to 1500 degrees Cent. (2732 degrees Fahr.) to cool to 1300 degrees Cent. (2372 degrees Fahr.) before pouring, gray castings were obtained. The slag cloud hypothesis *per se* would have suggested to most people that white castings should have been obtained after having cooled the superheated metal to 1300 degrees Cent. (2372 degrees Fahr.) before pouring. The introduction of the ideas al-

[1] Director, Ontario Research Foundation, Toronto, Ont.

ready referred to by the speaker enables an explanation of the facts to be made.

I should like to point out that the suggestion that a slag cloud can disappear as a result of solution in the melt is based upon good grounds. Some of you will recollect the results of the experiments described by me in a paper on oxides in brass, in which it is shown that the number of particles of oxide per cubic centimeter in a certain type of brass increased as the rate of cooling of the metal increased. In chill castings, for example, the number of particles per unit volume was high; in sand castings it was low. I feel that this is evidence that these oxides were soluble in molten brass; otherwise, it would have been impossible to get variations in the size of these particles with variations in the rate of cooling of the alloy. Hence, the idea is a reasonable one that a cloud (I should prefer to call it a "sonim cloud" rather than a "slag cloud") of nonmetallic particles can disappear on heating a metal or an alloy, as a result of their solubility in the melt.

DR. G. H. CLAMER:[2] I have been somewhat surprised that the researches of Prof. Girardet in connection with the subjecting of liquid cast iron to gyratory stirring have not had publicity on this side of the water. So far as I am aware, there has been no more than a mere mention of the same in our technical press.

Prof. Girardet is Professor of Metallurgy at the University of Nancy and a metallurgist of note; immediate Past-President of the French Technical Foundrymen's Association. He was awarded a gold medal by the Association for his discoveries and researches in that field. His first paper in connection therewith was published in 1929. He has published two or three subsequent papers and is scheduled to present an additional paper at the coming International Foundry Congress at Brussels.

He has shown that the structure of iron, without any change whatever in composition, is changed radically by subjecting it to gyratory action. The graphite of ordinary iron, which would be in flake form when cast, assumes the nodular appearance when cast after being gyrated. The number of graphite nuclei is greatly increased; namely, there is fine and even dispersion of graphite in nodular form. The physical properties of the iron so treated are improved appreciably.

I became interested in the work of Prof. Girardet and have carried on correspondence with him. In my first letter I asked him if he had ever stirred iron by the electro-magnetic forces prevailing in a coreless induction furnace and if he had done so, what were his results. In reply he stated that he had stirred iron in the coreless induction furnace but the results were quite different from those due to gyratory stirring. The stirring of the coreless induction furnace merely mixes the iron, making it more homogeneous, but it did not produce the same structural change. He had, however, produced gyratory form of stirring by electro-magnetic means and found the results were the same as with mechanical stirring.

It is claimed by Prof. Girardet also that non-metallic inclusions and gases are, to a great extent, expelled at the point of relative quiescence;

[2] President, Ajax Metal Co., Philadelphia, Pa.

namely, at the center of the churned mass of liquid iron. Churned iron, as he describes it, retains its heredity; namely, it can be remelted in the cupola or other furnace, after which the structure persists in the remelted and recast metal.

Prof. Girardet has made a few experiments that lead him to believe that beneficial results may follow the churning of non-ferrous alloys. Churning may be particularly desirable for the age-hardening of alloys.

We have made an arrangement to further study in this country the effects of gyratory stirring of iron and to determine definitely also if such stirring will modify and improve non-ferrous alloys.

I am deeply interested in the silicate slime or fog theory referred to by Messrs. Lorig and Dayton. It offers a quite satisfactory theoretical explanation of the effect of an insignificant percentage of deoxidizing agent added tc copper base alloys, particularly aluminum to yellow brass and phosphorus to the bronzes and brasses. I can readily picture in my mind an oxide fog acting as a nucleus for the individual grains of an alloy. It seems to me also that the fog theory may reasonably explain the effect of gyratory stirring. I can conceive of such action breaking up the fog and permitting therefore a different form of structural arrangement than if such fog were not dispersed.

In the discussion yesterday morning on Factors Affecting the Structure and Properties of Gray Cast Iron* I was impressed with the fact that there is yet no clear explanation of the effect of oxygen in such material. If oxygen is responsible for the fog formation, either as silicate or oxide in ferrous or non-ferrous alloys, and if such fog is responsible for the structural changes, it will be quite interesting to study the possibility of dispersing such fog and the effect of such fog on the structure and properties.

I am hoping to inaugurate a research program of this nature. I can recommend it enthusiastically, because of interesting possibilities. It is stated that churning in a ladle for a period of one to two minutes is sufficient for the purpose. No consequential drop in temperature will occur in that short time. No superheating is, therefore, necessary to compensate for the resulting heat loss.

DR. E. G. MAHIN:[3] The slag fog hypothesis appears to be an extremely reasonable one. These slag globules must be small before they can be large and there is every reason for supposing that after whatever ordinary separation of slag has taken place from any melted alloy, we must have remaining in that alloy microscopic and submicroscopic particles of the separating phase. Just how these particles may act, however, in connection with crystallization is another matter. The idea that slag particles act as the nucleii for crystallization was advanced, as we all recall, a good many years ago, I think by Ziegler. But at least in connection with iron-carbon alloys, I believe that hypothesis has been pretty largely abandoned. For example, in the freezing alloy one would expect to find particles largely in austenite crystals, when exactly the

* DiGiulio, A. and White, A. E., *"Factors Affecting the Structure and Properties of Gray Cast Iron,"* TRANS. A.F.A., vol. 43, p. 531 (1935), also June 1936, vol. 7, no. 3, p. 531.

[3] Head of Metallurgical Dept., University of Notre Dame, Notre Dame, Ind.

opposite is the case. If the presence of submicroscopic or microscopic particles prevents super-cooling, this would have an effect, of course, upon the grain size.

I am wondering whether this matter of super-cooling has actually been demonstrated experimentally? Super-cooling, of course, in any cooling system is not only common, it is universal. If super-cooling is large, naturally crystallization takes place more rapidly when it starts. But I do not know whether, in the cases discussed by the authors, experimental temperature measurements have proved super-cooling to be marked.

And, in this connection, as to the influence of particles of this sort upon grain size, I wonder whether the authors have considered another effect which is, of course, familiar to metallurgists, and that is the possible obstruction provided by these particles to grain growth? The presence of discrete particles of other phases has been shown to obstruct grain growth. And it seems quite reasonable to suppose that if the particles are of submicroscopic dimensions, or extremely small in dimensions, the obstruction to grain growth will become very marked. And one would expect with the slag or silicate fog formation—I do not suppose that this is limited to silicates, but any kind of slag-like material—the presence of these particles in enormous numbers and very minute in size and well distributed could well be regarded as a very efficient obstruction to grain growth. I should expect, therefore, that in a case like this grain growth would be inhibited and that we should get finer structures.

In connection with a point brought up by Mr. Ellis, the remark was made that superheating may cause re-solution of the particles, that also is to be expected. But superheating also may promote coalescence and separation of particles. I do not know whether the re-solution of the particles would have very much effect upon the size of these particles when they reappear because at all times, from the time the alloy is melted until finally cooled, whatever phases are in contact with the slag particles may be regarded as at least saturated with these particles. (Upon cooling, of course, they are super-saturated.) And they might reappear upon subsequent cooling. But the heating, super-heating perhaps, may not only redissolve these particles to some extent, as it would, but also may promote coalescence and separation of the particles.

SAM TOUR:[4] In the slag cloud hypothesis, pointed out here by the last speaker, there is a possibility that the formation of a slag cloud will inhibit grain growth and therefore result in a fine grain final product by such inhibition of grain growth rather than by acting as the nucleii for the origin of grains. In the paper, as presented, the attitude is apparently taken that the only effect of this slag cloud is to prevent under-cooling, and that the only method whereby fine grain size can be obtained is by under-cooling with the resultant sudden crystallization at many points.

Now, the slag cloud might be so finely dispersed and with so many particles present that it will give normal crystallization, that is, prevent under-cooling but still result in a fine grain. That the presence of such

[4] Vice president, Lucius Pitkin Inc., New York.

particles causes a coarsening of the grain and the formation of large grains would certainly not be true if sufficient of these particles were present to cause grains to commence to grow at many points. In other words, a slag cloud can cause fine grain size rather than coarse grain sizes indicated in the paper on page 3.

DR. C. H. LORIG: There are a few points that I wish to discuss. I think Mr. Tour brought up an important point which we did not make clear. We did not want to indicate that the presence of a large number of inclusions would not give fine grain structures. I realize the whole question is rather difficult to discuss because of two effects, first, the possible effect of having just the right number of inclusions there to cause grain growth, and second, the possible effect of having an excess or an insufficient number of these small particles to cause refinement of grain. I am afraid the paper did not emphasize this point, consequently I appreciate Mr. Tour's statement calling our attention to the fact.

The basic idea we wanted to bring out was the fact that slag clouds might influence crystallization of non-ferrous alloys as well as of ferrous alloys.

In regard to the other discussions, I quite agree with Dr. Ellis that some of the inclusions may be dissolved at super-heated temperatures. They may come out again, as he apparently showed with experiments on cast iron, when the metal is cooled slowly enough. Whether inclusions come out of solution or whether they do not will of course influence the structure of the metal decidedly. The addition to the slag-cloud hypothesis which Mr. Ellis has offered is a valuable contribution and it is appreciated.

The remarks by Prof. Mahin and by Dr. Clamer are both very interesting and very instructive.

Studies on Solidification and Contraction in Steel Castings-III,— The Rate of Skin Formation**

By C. W. Briggs* and R. A. Gezelius,* Washington, D. C.

Abstract

The rate of skin formation in steel castings is the subject of the third paper of a series presented by the authors before this Association on the solidification and contraction of steel castings. In this paper, the factors that would influence the velocity of solidification of a steel casting, and the rate at which the skin forms are discussed. Studies were made on shapes of varying volumes and also on shapes with varying surface area and a constant volume. The numerical values obtained were used to calculate constants and formulas of solidification and to evaluate the importance of the theoretical considerations.

1. The primary function of a mold is to provide a receptacle for the molten steel; however, a further important function is to abstract heat from the molten steel and to dissipate it. The process of abstraction of heat proceeds by two methods that are not entirely independent. The first is the chilling action that the cold mold has upon the molten steel, and the second is the outward passage of heat by conduction through the walls of the mold.

2. The thermal conductivity of the mold material, its specific heat and density, affect the rate at which heat can be extracted from the center of the steel casting. The degree of the initial chilling action of the mold will depend on the relative specific heats of the steel and the mold materials. For sand molds of the same dimensions, the greater the thermal conductivity, the greater will be the rate of cooling. If the sand molds are made of the same material then the thicker the mold walls the slower will be the rate of cooling. Owing to the poor thermal conductivity of molding sand, the decrease will not be proportional but will tend to a limiting value, beyond which greater thickness of sand will have little effect on the rate of cooling. Thus, the conditions which determine solidification may be classified as external and internal. The exter-

* Division of Physical Metallurgy, U. S. Naval Research Laboratory.

** Published by permission of the Navy Department.

Note: This paper was presented at a session on Steel Founding held at the 1935 Convention of A.F.A. in Toronto, Canada. The two previous papers in this series are listed as references 11 and 12 of the bibliography appearing on page 296.

nal conditions are those which initiate and control the cooling of the steel and are determined by the mold characteristics; the internal conditions govern the cooling effect within the casting and are determined by the physical properties of the steel.

3. The procedure of solidification of steel, especially of ingot solidification, has been studied by several investigators, notably, Desch[1],† Matuschka[2], Benedicks[3], Fields[4], Nelson[5], and others. The committee on the Heterogeneity of Steel Ingots of the Iron and Steel Institute[6] has perhaps accomplished the most through its series of reports. These investigators explain fully the operation of freezing. In general, the cooling of the steel at first takes place chiefly by absorption of heat by the mold walls. Subsequently, cooling proceeds by transmission of heat through the mold. These two cooling actions occur simultaneously, but the first starts from a maximum value and decreases with time, and the second starts from a minimum value and increases with time up to a certain point when it slowly decreases again. The first action (chilling) is capable of freezing at any part of the mold a considerable mass of steel. The freezing, therefore, can be considered to occur in three successive periods:

(1) Almost instantaneous freezing.
(2) Very rapid freezing.
(3) Comparatively slow freezing.

4. At the time of rapid solidification of the crust, a decrease in temperature in the interior of a large casting is not noticeable while the molten metal lying adjacent to the chilling surface will pass rapidly through the range between the superheated temperature and the freezing temperature. The rapid solidification is followed by a slower decrease in the lower superheat temperatures.

5. Due to the low heat conductivity of a sand mold, the velocity of solidification may be so slow that the excess temperature of the molten steel is dissipated before solidification has reached the central portion of the casting. Subsequently, the frozen zone conducts only the heat of solidification, while the portion still molten remains at a fixed temperature—the freezing temperature.

6. The chief factors influencing the solidification of steel castings are:

(1) Type, shape, and size of mold.

† Numbers refer to articles included in the bibliography.

(2) Temperature of the steel above its melting point (superheat).
(3) Physical properties of the steel.
(4) Temperature of the mold.

These various factors may be considered more fully.

TYPES, SHAPES, AND SIZE OF MOLDS

7. The types of molds or mold compositions do not vary widely for, in most cases, they are composed of sand. Some types of molds are made in such a manner that they will collapse after pouring. In such cases, relieving blocks, coke, straw rope, and the like are placed in the backing sand. These materials break up the continuity of the sand extending from the mold-metal interface to the exterior of the mold and thus change the thermal conductivity. Whether or not there would be a perceptible change in the velocity of solidification or the rate of skin formation has not been studied, but it is thought that it would be very small.

8. Changes in the solidification velocity may be obtained by the use of various mold materials, but unlike the ingot mold where the use of copper leads to a considerable increase in the velocity of solidification over the usual cast iron mold, the variation in sand molds would result in possibly little more than a perceptible change. This point will be taken up in detail in discussing the experimental data.

9. Other factors influencing the velocity of solidification are the shape and size of the mold. The characteristics of the mold determine the length of time it takes before solidification is complete. As the rate of cooling decreases, the time required for the steel to pass through the freezing range increases and the velocity of solidification is altered. The shape and size of the mold also governs, to a certain degree, the temperature gradient throughout the steel casting for, in small sections, the chilling effect may bring about complete solidification, whereas in large molds solidification will proceed for considerable periods after the chilling action has been exhausted.

TEMPERATURE OF THE STEEL ABOVE ITS MELTING POINT

10. The initial rate of skin formation is decreased by pouring castings with superheated steel. This is explained by the fact that the excess heat must first be extracted from the superheated steel before solidification can begin. The effect of superheat on the solidification of ingots was studied experimentally by Matuschka[2]

and calculated by Schwartz[7]. The effect of superheat on the solidification of steel in a sand mold is shown in Fig. 1. For comparison the curve calculated by Schwartz to indicate the rate of solidification of a steel ingot is reproduced. It will be noticed that the effect of superheat on the velocity of solidification of steel is not as great in a sand mold as it is in a cast iron mold.

11. R. Heggie[8] has pointed out that his experimental data on cooling curves indicated that a state of dynamic heat balance exists in a freezing mass. The data obtained by B. Matuschka on plain carbon and nickel-chrome steels corroborates this theory.

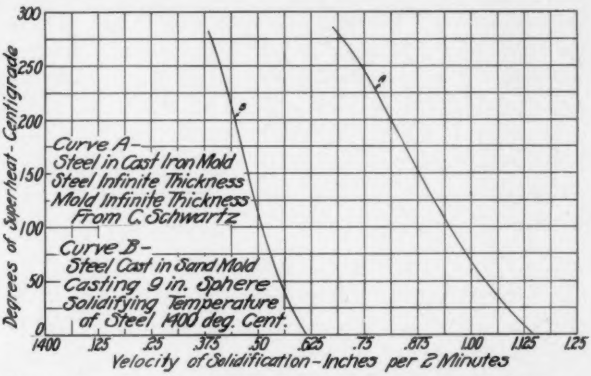

FIG. 1—EFFECT OF SUPERHEAT ON THE VELOCITY OF SOLIDIFICATION.

The term "dynamic heat balance" is used to denote that the latent heat evolved in freezing at any particular moment is just sufficient to balance the heat removed at the surface of the mold.

12. Many producers of steel castings assume that as steel solidifies, it passes through a pasty or mushy state of low viscosity. Professor Andrews[9] in discussing this subject stated that when a determination of the freezing point of a steel was made it was found that the greater mass of the steel became solid at a constant temperature, even though there were rather wide differences between the liquidus and solidus. This showed that a greater portion of the steel became solid and that a very small amount of liquid remained.

13. In a discussion on the same subject, C. Desch[6a] stated that there is no evidence for the assumption that liquid steel becomes very viscous or passes into a pasty stage since the viscosities of molten metals are low, even close to the melting point. While

there is no data as to the actual viscosity of molten steel, there is no reason to suppose that it differs in that respect from other metals, and common experience would suggest that steel is highly fluid. It thus differs from molten silicates, which are extraordinarily viscous when first melted and become fluid only at temperatures far above their melting point. That is explained by their degree of molecular association; but metals, including steel, are known, from the lowering of their freezing points and from other facts, to consist mainly of single atoms. Their viscosity should, therefore, be low.

14. The authors' experimental work corroborates the points brought forward by Professors Andrews and Desch. There is, in castings that have been bled late in their solidification, porous steel adhering to the walls of the cavity. The presence of this condition is due to the slow transition from the liquid to the solid state and consists of an aggregate of crystal skeletons, continuous in the sense that the projections of adjacent skeletons touch one another or have grown together, but containing liquid steel in the interstices.

Temperature of the Mold

15. The rate of solidification of a metal in a mold depends, to a certain extent, upon the temperature of the mold prior to pouring. A. Schwartz has calculated that for steel ingots poured into cast iron molds, heating the mold is equivalent to superheating the steel. It is, therefore, evident that the rate of solidification is less in molds heated prior to pouring.

16. It has been assumed that, with ordinary pouring conditions, the temperature at the mold-metal interface immediately after pouring is 1100-1200 degrees Cent. (2012-2192 degrees Fahr.) in a sand mold and 900-1000 degrees Cent. (1652-1832 degrees Fahr.) in a cast iron ingot mold. In view of the difficulties of experimental determination, the steepness of the temperature gradient between the exterior of the casting and its axis has been largely a matter of surmise. Calculations have been made on ingots by N. Lightfoot[6c, d] and by S. Saito[10] which quite fully set out the temperature gradients that may be expected in an ingot. A study of temperature gradients of a 9-in. diameter sphere casting was made both as to the metal temperature gradient and the mold temperature gradient. These data are set forth in Fig. 2. In this study, a platinum and platinum-rhodium thermocouple was placed at the center of the sphere, another at the mold-metal interface and

a third on the radius of the sphere midway between the other two. The temperatures indicated by these thermocouples were all read on one millivoltmeter at intervals of 45 seconds. The temperature of the sand surrounding the sphere was also noted at several points. The data shows that there is a difference of 350 degrees

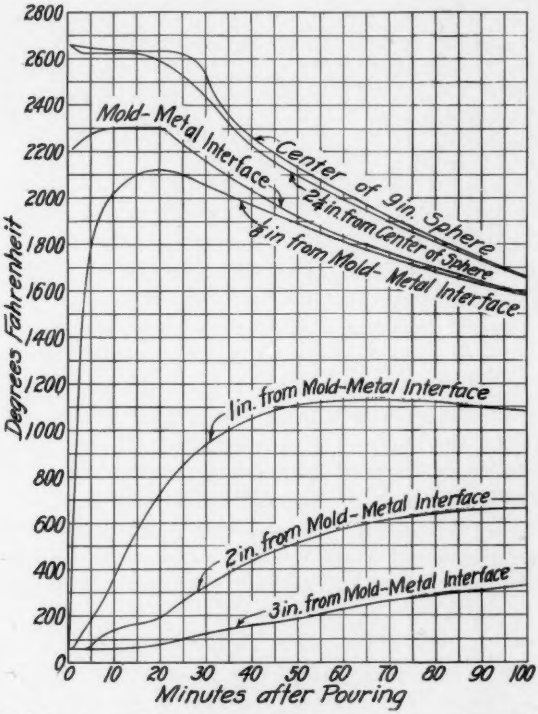

FIG. 2—TEMPERATURE GRADIENTS IN METAL AND MOLD IN A 9-IN. DIAMETER SPHERE CASTING.

Fahr. between the center of the sphere and the mold metal interface during the first 20 minutes of cooling of the casting. This variation in temperature decreases after solidification of the sphere is completed. The magnitude of the temperature gradient that exists within the mold is also pointed out by the data.

17. It is not the purpose of the authors to enter into a discussion of the macro- and microstructures of cast steel, the dentritic formation, or the zones of chill, columnar, and equiaxed structure,

but it would seem advisable to enumerate some of the phases of crystallization.

18. The first contact between molten steel and the mold wall will immediately cool down a surface layer of steel to such low temperatures that, in accordance with the results of the well-known investigations by Tammann and Miers, numerous nuclei will be formed. How many nuclei will be formed in a given mass is evidently a problem in probability. Examination of sections of cast steel of the same composition and cast at the same time in similar molds will show that the number of crystals does not vary widely.

19. The distribution of the nuclei is not entirely a random one. The first nuclei, those that originate in contact with the walls of the mold, are probably very numerous, but comparatively few of them grow to such a size as to penetrate far into the mass. The separation of the first crystals from the liquid undoubtedly occur under metastable conditions, the crystals which had already formed bringing about further crystallization by contact. As cooling proceeds, a stage is reached at which fresh nuclei appear spontaneously in the liquid preceding the advancing solid zone. Thus, it is seen that the number and arrangement of the nuclei are responsible for the form and dimensions of the crystal grains, and going back one step further, the number and arrangement of the nuclei depend upon the temperature distribution in the casting.

20. The temperature distribution is defined at every point either (1) by the temperature gradient, indicative of the direction of the maximum heat flow, or (2) by the direction at right angles to this, that is, the isotherm which intersects this point.

PROCEDURE USED IN OBTAINING DATA

21. The design of the castings used to obtain data on the progress of solidification must be simple so that the data can be reproduced with a fair degree of accuracy. The design chosen for the preliminary work on this problem was a 6-in. diameter sphere with a 2-in. diameter central down-gate. This design is simple, is easily bled through the top gate and its thickness of 6 in. is not uncommon in large steel castings.

22. The pattern was molded in Downer sand, the properties of which, in the dried state, are:

Permeability	87	c.c./min.
Compression Strength	93.5	lb./sq. in.
Shear Strength	29.5	lb./sq. in.
Tensile Strength	2.9	lb./sq. in.

23. A thin coating of an emulsified linseed oil mold wash was sprayed on the surface of the molds and the molds dried at 400 degrees Fahr. for 20 hours. The temperature of the molds at pouring time was about 100 degrees Fahr. The steel was poured into the sphere through the down-gate until the down-gate was full. The time was noted at the moment the mold was full, a predetermined period of time was allowed to elapse and then the mold was turned over so that the steel that had not solidified could run out of the mold. The casting was then cooled, shaken out of the mold, and cut in half on the diameter perpendicular to the down-gate. The thickness of the skin was then measured, the accuracy of the measurements being about $\pm 1/64$ in. It was impossible to measure closer than this due to the irregularity of the inner surface.

24. The lower halves of the spheres were weighed and the weights reported on the entire sphere by doubling the weight obtained.

25. About 65 determinations were made during the preliminary stage of this study. This preliminary work brought out the need for changes in the procedure. The diameter of the pouring gate was increased to 4 in. as the two inch gate froze over before the desired time intervals prior to bleeding had elapsed. It was found that even the 4-in. diameter gate could not be kept open as long as was desired and so "thermit" was used to keep the steel in the gate molten. It was proven experimentally that the use of thermit did not affect the rate of solidification in the sphere to any extent, but this method was also discarded. The method finally adopted consisted of filling the pouring top to a definite level which was determined by a spillway cut into it. With this extra amount of metal in the hot-top, the gate can be broken off with a large hammer and the liquid steel poured out.

26. In the preliminary experiments, data was collected at several bleeding times during one heat. As these results could not be correlated, it was decided to devote the entire heat to one bleeding time. The results obtained with this system were much better and this procedure was used during the remainder of the study.

27. After the initial trials on the 6-in. diameter sphere had been completed, it was recognized that further data would be useful in order that an attempt could be made to correlate the rate of skin formation of solids with identical volumes but varying surface areas. Therefore, several parallelepipeds were designed with

the same volume as the 6-in. diameter sphere but with surface areas that were 35, 60, and 110 percent greater than that of the sphere.

28. In considering the volume of the sphere, it was assumed that the total volume of the sphere was active even though a small portion of the sphere did lie within the pouring gate. The metal in the gate probably affects the skin formation of the entire sphere to some extent, but the effect is most marked at the junction of the gate and the sphere. The effect of the larger gates on the skin formation at the diameter where measurements were taken is small for several 6-in. diameter spheres with 2-in. and 4-in. diameter gates and several 9-in. diameter spheres with 4-in. and 6-in. diameter gates were cast and bled after the same period of time had elapsed. There were no measurable differences in skin thickness due to the increase in the size of the gates.

29. The surface area of the sphere was considered to be only the 100 sq. in. exposed to the sand rather than the total surface area of a 6-in. diameter sphere. The dimensions of the patterns for the parallelepipeds designed to have the same volume as a 6-in. diameter sphere but greater surface areas are given below:

$3\frac{5}{8}$ x $3\frac{5}{8}$ x $8\frac{5}{8}$ in. —Surface area 35 percent greater than that of a 6-in. diameter sphere.

$2\frac{1}{4}$ x $6\frac{1}{4}$ x 8 in. —Surface area 60 percent greater than that of a 6-in. diameter sphere.

1 25/64 x $10\frac{5}{32}$ x 8 in.—Surface area 110 percent greater than that of a 6-in. diameter sphere.

30. The rates of solidification of 3, 4.5, and 9 in. diameter spheres also were studied in order that the effect of volume on the rate of skin formation might be noted.

31. The effect of pouring temperature on the rate of solidification was shown by pouring several 6-in. and 9-in. diameter spheres at a comparatively high temperature (2940 degrees Fahr.), holding the heat for some time and pouring the remaining spheres at a lower temperature (2620 degrees Fahr.).

32. The influence of mold material on the rate of solidification was noted by pouring alternately spheres molded in the usual dried sand and spheres molded in a typical synthetic green sand.

33. A pattern was prepared in which three cylinders of 2, 4 and 6-in. diameter and 3, 3 and $3\frac{1}{2}$ in. in height, respectively, were joined together. This casting was poured with the large end up and bled at various times so that the effect that the sections of different size had upon each other might be noted. The readings of thickness of skin obtained at an interval of five seconds after pour-

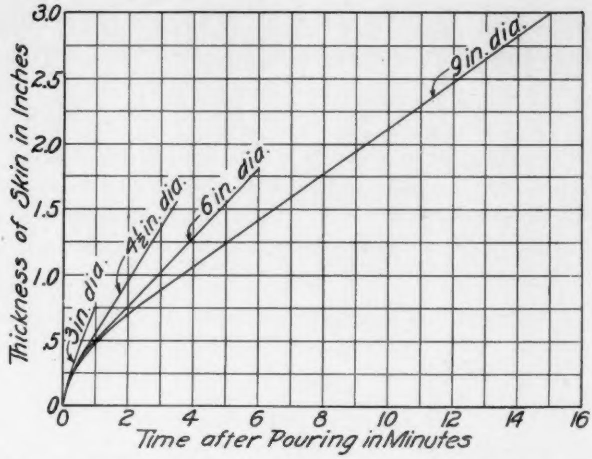

FIG. 3—RATE OF SKIN FORMATION OF 3, 6 AND 9-IN. DIAMETER SPHERES.

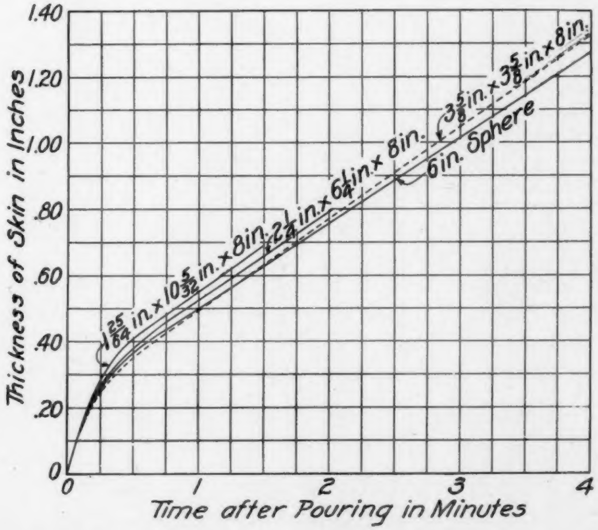

FIG. 4—RATE OF SKIN FORMATION OF PARALLELEPIPEDS COMPARED WITH SKIN FORMATION RATE OF 6-IN. DIAMETER SPHERE.

ing were as close to a zero time interval as could be obtained. It required this much time to move the ladle away and overturn the mold.

EXPERIMENTAL DATA

34. In the study of the rate of solidification by bleeding various sizes of spheres and parallelepipeds, 388 determinations were made which established 38 points. These determinations were averaged and the data are presented in Table 1 and shown graphically in Figs. 3 and 4.

35. In order that a study could be made of the effect of the

Table 1

THICKNESS OF SKIN IN INCHES

	Spheres				Parallelepipeds		
Time	3 in. Dia.	4.5 in. Dia.	6 in. Dia.	9 in. Dia.	$3\frac{5}{8}$ x $3\frac{5}{8}$ x 8 in.	$2\frac{1}{4}$ x $6\frac{1}{4}$ x 8 in.	$1\frac{25}{64}$ x $10\frac{5}{32}$ x 8 in.
5 sec.	0.15	....	0.14	0.14	0.13	0.14	0.15
30 sec.	0.45	0.40	0.37	....	0.35	0.38	0.41
45 sec.	....	....	....	....	....	....	0.50
1.0 min.	0.75	0.54	0.50	0.48	0.49	0.53	0.57
1.5 min.	....	0.67	....	....	....	0.64	....
2.0 min.	....	....	0.76	....	0.76	0.82	....
3.0 min.	....	....	1.00	0.90	1.04	....	....
3.5 min.	....	1.55	....	....	....	....	....
4.0 min.	....	....	1.29	....	1.40	....	....
5.0 min.	....	....	1.54	....	....	....	....
6.0 min.	....	....	1.80	1.34	....	....	....
9.0 min.	....	....	....	1.93	....	....	....
12.0 min.	....	....	....	2.48	....	....	....
15.0 min.	....	....	....	3.00	....	....	....

size of a casting on the rate of skin formation, a series of spheres of different diameters were bled at various time intervals. If the volume of the 6-in. diameter sphere is considered as unity, the volumes of the other spheres compare as follows:

Diameter, in.	Volume, cu. in.	Volume Ratio
9	382	3.44
6	113	1.00
4.5	48	0.43
3	14	0.12

36. It will be noticed that the volumes differ considerably and

Table 2

Volume of Steel Solidified per Square Inch of Surface Area

	Spheres								Parallelepiped							
	3 in. Dia.		4.5 in. Dia.		6 in. Dia.		9 in. Dia.		$3\frac{5}{8}$ x $3\frac{5}{8}$ $8\frac{5}{8}$ in		$2\frac{1}{4}$ x $6\frac{1}{4}$ x 8 in.		$1\frac{25}{64}$ x $10\frac{5}{32}$ x 8 in.			
Time	Lbs. Steel Solidified	Lbs. per sq. in. of surface area	Lbs. Steel Solidified	Lbs. per sq. in. of surface area	Lbs. of Steel Solidified	Lbs. per sq. in. of surface area	Lbs. Steel Solidified	Lbs. per sq. in. of surface area	Lbs. of Steel Solidified	Lbs. per sq. in. of surface area	Lbs. of steel Solidified	Lbs. per sq. in. of surface area	Lbs. of Steel Solidified	Lbs. per sq. in. of surface area	Avg. Lbs. per sq. in. of surface area	Cu. in. solidified per sq. in. of surface area
5 sec.	1.0	0.037	....	.....	4.2	0.038	9.8	0.038	5.7	0.038	6.2	0.038	8.6	0.038	0.038	0.134
30 sec.	2.6	0.093	6.0	0.094	10.4	0.092	.....	.....	14.1	0.093	15.3	0.092	21.1	0.094	0.093	0.329
1 min.	3.5	0.123	7.7	0.121	13.4	0.119	31.1	0.122	18.3	0.122	19.8	0.121	27.6	0.123	0.121	0.427
1.5 min.	....	.....	8.8	0.138	....	.....	.....	.....	....	.....	22.6	0.137	....	.....	0.138	0.488
2.0 min.	....	.....	....	.....	18.5	0.164	.....	.....	24.8	0.163	26.9	0.165	....	.....	0.164	0.579
3.0 min.	....	.....	....	.....	22.5	0.199	52.7	0.207	30.9	0.204	....	.....	....	.....	0.204	0.721
4.0 min.	....	.....	....	.....	26.1	0.228	.....	.....	34.8	0.232	....	.....	....	.....	0.230	0.813
5.0 min.	....	.....	....	.....	27.3	0.243	.....	.....	....	.....	....	.....	....	.....	0.243	0.859
6.0 min.	....	.....	....	.....	30.0	0.265	70.6	0.277	....	.....	....	.....	....	.....	0.271	0.957
9.0 min.	....	.....	....	.....	....	.....	87.9	0.354	....	.....	....	.....	....	.....	0.354	1.251
12.0 min.	....	.....	....	.....	....	.....	99.6	0.391	....	.....	....	.....	....	.....	0.391	1.382
15.0 min.	....	.....	....	.....	....	.....	104.0	0.408	....	.....	....	.....	....	.....	0.408	1.442

that the rate of skin formation apparently increases as the volume of the sphere decreases.

37. In the second phase of the investigation, it was planned to study shapes that have the same volume but varying surface areas. The volume of the 6-in. diameter sphere was chosen as constant and parallelepipeds were selected giving the same volume with 35, 60, 110 percent greater surface area.

38. An explanation is necessary concerning these data. It was found that, on taking linear measurements, the sides of the parallelepipeds were thinner than the corresponding values obtained for the 6-in. diameter spheres but that the corners were considerably thicker due to the well known "corner effect" of solidification. This variation in the thickness made it practically impossible for an average thickness to be obtained by measurement, thus it was calculated from the volume of steel solidified.

39. It can be seen from Fig. 4, where the calculated average linear thickness is plotted against time, that the greater the surface area the faster is the rate of skin formation. The differences obtained are, however, small and in the case of the parallelepiped with 35 percent greater surface area, the increase in rate is nearly negligible. This is in line with the preliminary results, as reported in an earlier paper of this series[11].

40. It should be noted, Table 2, that even though the linear rate of skin formation varies with the volume of the spheres and also to a slight degree with the surface area of solids with identical volumes, the velocity of solidification is a constant. That is, at any definite time after pouring the weight of steel solidified, or the volume of steel solidified, per square inch of mold surface is the same. These data are shown graphically in Fig. 5. Using this curve, it was possible to predict with a fair degree of accuracy, the skin thickness and weight of a 4.5-in. diameter sphere bled 3.5 minutes after pouring.

41. It has been pointed out that there are three phases in the solidification of a casting; (1) almost instantaneous freezing, (2) very rapid freezing, and (3) very slow freezing. These transitions are shown in Fig. 6, where the rate of solidification in cu. in. per min. is plotted against time. It should be noted that the initial rate of solidification (due to chilling by the mold) is very high but decreases very rapidly to a second phase of solidification that is rapid but which in turn decreases to a very slow rate of freezing.

42. The number of measurements required to obtain sufficient

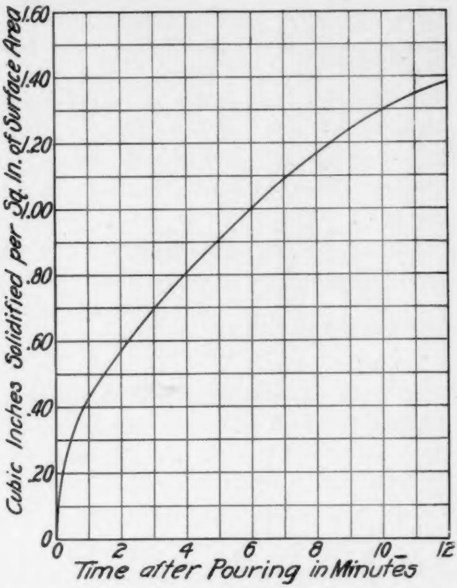

FIG. 5—RATE OF SOLIDIFICATION OF STEEL IN DRY-SAND MOLDS, WITH RELATION TO SURFACE AREA.

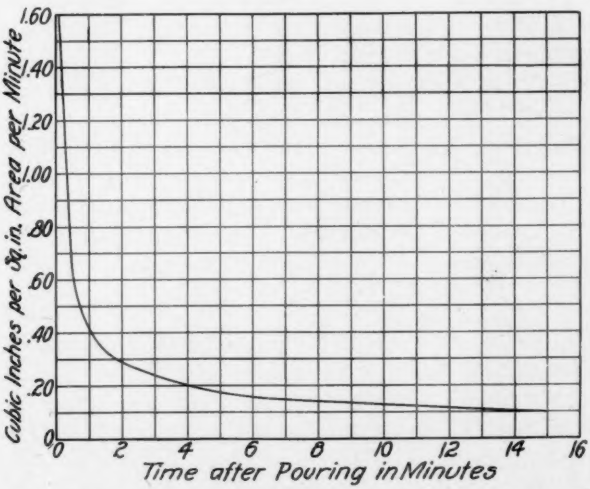

FIG. 6—RATE OF SOLIDIFICATION OF STEEL IN DRY-SAND MOLDS BASED ON VOLUME SOLIDIFIED.

data to determine the rate of skin formation on the various solids listed above, necessitated numerous different heats of steel. As it was impossible to obtain steel of the same analysis each time, it was decided to vary the carbon, manganese, and silicon contents within the usually allowable limits of cast carbon steel to detect the influence of the composition on the rate of skin formation. It was found that the differences, if any, were all within the limit of error in measurement.

43. The difficulty of taking measurements of a high degree of accuracy should be appreciated for the inner surface of the bled casting varies from extreme unevenness in the case of castings poured at high temperatures to smooth inner surfaces in castings poured at low temperatures.

44. As each mold was poured, a temperature reading of the molten steel entering the mold was made with an optical pyrometer. Thus, a study at any one bleeding time consisted of a range of castings poured from high superheat temperatures to low superheat temperatures. All these values were averaged to give the point for a definite bleeding time. In this way, a fair average was obtained.

45. The ideal situation for filling the mold instantly could not be attained, of course. Two things were done to overcome this. First, an attempt was made to pour the molds at the same pouring speed, and secondly, to take the measurements always on the horizontal diameter; in this manner the error due to the time required to pour the mold was at a minimum.

46. It has been stated that the variation in molding materials would result in little more than a perceptible change in the velocity of solidification. The extent of this variation was the object of a study wherein both dry and green sand molds were used. The molds (6-in. diameter spheres) were poured alternately and all bled at a time interval of two minutes. The averages obtained were:

Mold Type	Skin thickness, in.	Weight, lb.
Green sand	0.75	18.6
Dry sand	0.74	18.3

47. The results are within the limit of error of measurement. The data tend to show that the rate of solidification is practically the same in either of the common types of green or dry sand. This might be expected, as the rate of heat transference of these two sands is not appreciably different, as shown in Figs. 8 and 9. The rate of heat transference in sands of different types can vary greatly, as is shown in Figs. 7 and 10. The Chamotte, a European

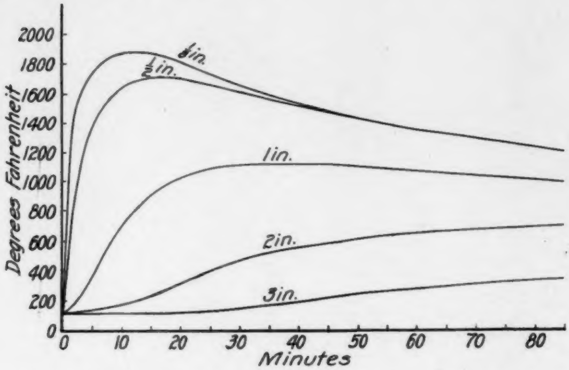

Fig. 7—Heat Transference Rate of Chamotte Sand, a European Sand with High Permeability.

molding material, has a very high rate of heat transference, due primarily to the rapid heat transference by radiation through the large air spaces between the grains. The permeability of this molding material is 2000 cc. per min. or greater in the green state. The cement-bonded sand has unusually low heat conductivity, due to its low permeability and the more or less refractory cement used as a bonding material. More detailed information on this subject appeared in an earlier publication[12].

48. It has been pointed out previously that the pouring temperatures of each mold was taken with an optical pyrometer and that in this way a study of the effect of temperature on the rate of

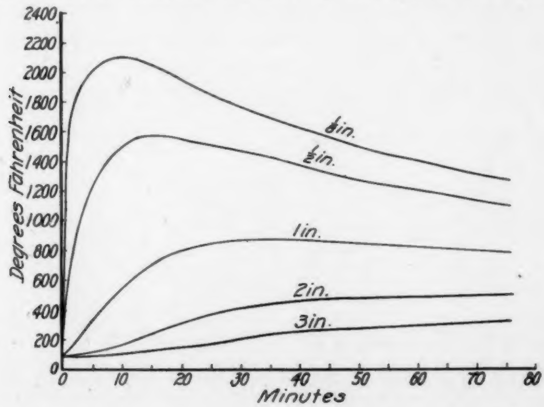

Fig. 8—Heat Transference Rate of Downer Sand.

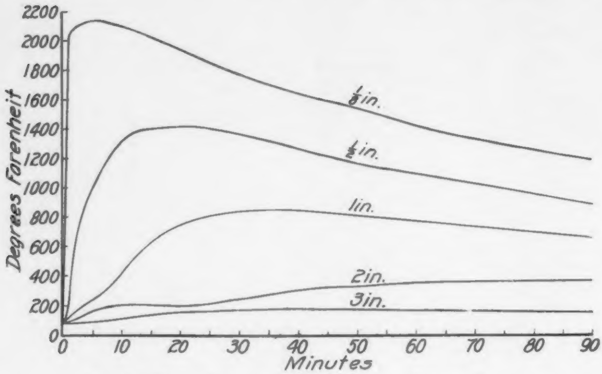

FIG. 9—HEAT TRANSFERENCE RATE OF GREEN SAND.

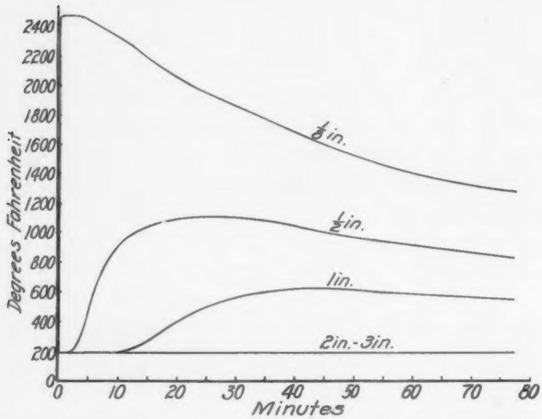

FIG. 10—HEAT TRANSFERENCE RATE OF CEMENT-BONDED SAND.

skin formation could be attained. A typical condition found is reported as follows:

Sphere Diameter, In.	Bleeding Time, Min.	Thickness, In.	Weight, Lb.	Internal Cavity Vol., cc.	Temp., Degrees Fahr.
9	6	1.35	67.2	2130	2940
9	6	1.50	73.2	1850	2620
6	3	1.01	21.4	615	2930
6	3	1.07	22.4	525	2630

This type of data leads to the general curve as shown in Fig. 1.

49. A further study of the effect of shape and size of molds

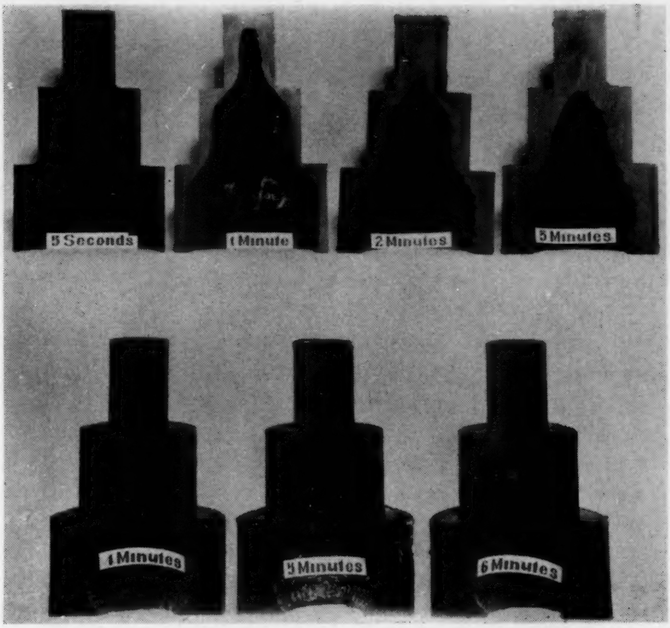

FIG. 11—RATE OF SKIN FORMATION IN JOINED CYLINDERS.

on the rate of skin formation was made. These results, obtained by bleeding the mold composed of three cylinders, are shown in Fig. 11. The object of this experiment was to determine whether or not the linear rate of solidification of one cylinder would be changed by being connected to a larger cylinder. The volumes, surface areas, and ratio of surface area to volume of each cylinder are given below:

Cylinder Dia., in.	Cylinder Height, in.	Volume, Cu. in.	Area, Sq. in.	Area / Volume
2	3	9.42	21.98	2.20
4	3	37.68	47.06	1.25
6	3½	98.94	81.65	0.82

50. It should be noted that even though the volume of each section is considerably different and the ratio of surface area to volume decreases rapidly, the castings that were bled at 5 seconds, 1 minute, and 2 minutes show no differences in linear solidification

in the three sections. After 2 minutes, this is no longer true as the "corner effect", due to the heat being conducted away from one corner more rapidly than the other, has overshadowed the solidification perpendicular to the cylinder walls.

51. It should also be noted that even on the casting overturned as soon as possible after pouring (5 seconds), each small corner of sand at the base of the cylinders has been overheated so that the steel envelope is very thin at these points. Also, the center corners of the cylinder are already thicker than the walls of the cylinder. Both of these effects could have been minimized by increasing the radius of the corner.

CALCULATIONS

52. The solidification of ingots has been studied theoretically by Saito[10], Fields[4], Lightfoot[6c, d], and Schwartz[7]. These investigators have calculated, among other things, the velocity of solidification in an ingot. In general, they have all arrived at somewhat the same formula which tends to show that the velocity of solidification is a parabolic function.

53. Saito used a very complicated formula in his calculations and obtained some very good results which were excellently substantiated by Heggie[8] with studies on the solidification of steric acid. Fields' formula gives the solidification thickness as:

$$D = K\sqrt{t}\ ;\ \text{with } K = 0.88$$

where D is the total distance through which solidification has progressed in time t and K is a constant of solidification. The formula used by Lightfoot was the same as that of Fields except for the value of K.

$$D = K\sqrt{t}\ ;\ \text{where } K = 0.34.$$

A slight difference is recorded by Schwartz, who gives the following formula:

$$D = \tfrac{1}{2}\frac{q}{\sqrt{t}}$$

where q is a constant of solidification.

54. After performing a series of experiments on the bleeding of ingots, Nelson[5] attempted to fit his data to the formula developed by Fields and found that the data corresponded very well in the early stages of solidification, but that as solidification proceeded his data deviated further from the theoretical curve. Just how the theoretical data would compare with the experimental data obtained in the study of steel cast into sand mold was of interest.

The manifested differences of the two methods would undoubtedly result in a modified value for K, the solidification constant.

55. Several attempts were made to fit the general curve

$$D = K\sqrt{t}$$

to the experimental data. It was found, however, that this equation could be used successfully only on the lower portion of the curve. These data appear to fall upon a hyperbolic rather than a parabolic curve but a fairly good fit can be obtained using the general equation

$$D = K_1\, t^{.4} + K_2 t$$

where K_1 and K_2 are constants depending upon the shape of the mold, etc. The equations that were found to represent the cases studied with a fair degree of accuracy are shown graphically in Figs. 12, 13, 14, and given below.

Sphere Diameter, in.		Equation
9	—	$D=0.342\ t^{.4}+0.125t$
6	—	$D=0.346\ t^{.4}+0.172t$
3	—	$D=0.309\ t^{.4}+0.428t$

56. It should be noted that the constant of first term of the equation which controls the lower portion of the curve, and therefore indicates the chilling action of the sand, is practically the same in each case. The constant of the second term of the equation which controls the upper, straighter portion of the curve, and there-

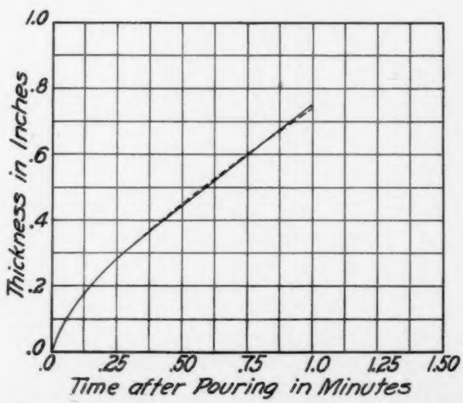

FIG. 12—RATE OF SKIN FORMATION OF 3-IN. DIAMETER SPHERE. THE SOLID LINE REPRESENTS THE CURVE OBTAINED FROM ACTUAL DATA AND THE BROKEN LINE, VALUES CALCULATED FROM THE EQUATION, $D = 0.309t^{.4} + 0.428t$.

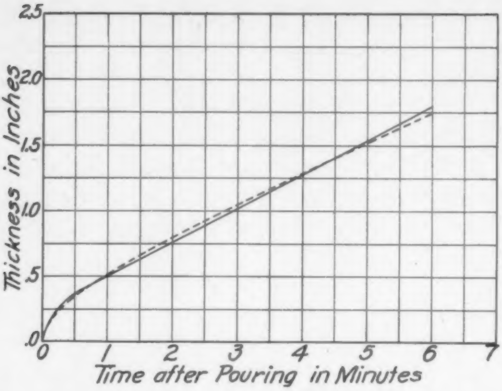

FIG. 13—RATE OF SKIN FORMATION OF 6-IN. DIAMETER SPHERE. THE SOLID LINE REPRESENTS VALUES OBTAINED FROM ACTUAL DATA AND THE BROKEN LINE, VALUES CALCULATED FROM THE EQUATION, $D = 0.346t^{.4} + 0.172t$.

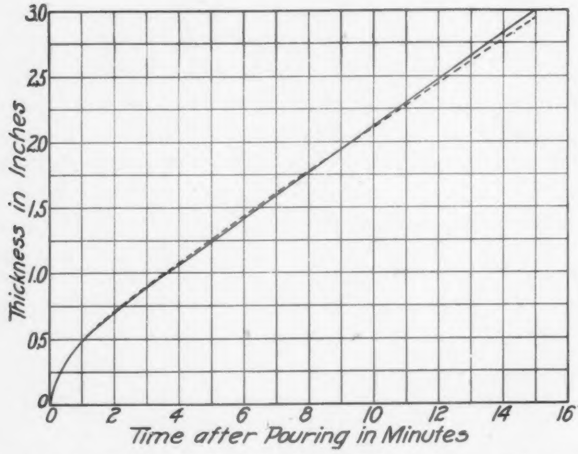

FIG. 14—RATE OF SKIN FORMATION OF 9-IN. DIAMETER SPHERE. THE SOLID LINE REPRESENTS VALUES OBTAINED FROM ACTUAL DATA AND THE BROKEN LINE, VALUES CALCULATED FROM THE EQUATION, $D = 0.342t^{.4} + 0.125t$.

fore represents the solidification due to the heat conducted away by the mold, decreases as the volume of the casting increases.

57. Previous investigators have attempted to obtain theoretically an equation that would represent the rate of skin formation with respect to time. The authors believe that although it is possible to obtain a general equation to represent this phenomenon, the

constants used will vary for each particular case studied. They also believe that the velocity of solidification, that is, the volume of steel solidified per square inch of mold area is practically constant under ordinary working conditions. Therefore, further study of this phenomenon should result in information very useful to both the foundryman and the designer in the planning of future castings.

Summary

58. The following summary of the points as brought forward in the paper are:

(1) The rate of skin formation increases as the volume of the steel casting decreases.

(2) The greater the surface area of a steel casting the faster is the rate of skin formation.

(3) The velocity of solidification is a constant; that is, at any definite time after pouring the volume of steel solidified per square inch of mold surface is the same.

(4) Variations in the ordinarily used molding materials results in little more than a perceptible change in the velocity of solidification.

(5) The degree of superheat modifies the rates at which the skin forms.

(6) Calculations of the rate of skin formation can be made and predicated in various sizes of sphere castings.

Acknowledgment

59. The authors wish to express appreciation to the various members of the Naval Research Laboratory staff for their assistance in the research problem; Messrs. J. Darby, A. R. Donaldson, T. Cunningham, for manipulating the molds to be bled; L. Singer for chemical analysis; J. Lee for help with the calculations, and Dr. R. H. Canfield for advice and counsel.

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DISCUSSION

GEORGE BATTY[1]: (*Submitted in Written Form*): In discussing this paper, the third of a series by the authors, I am moved to comment that it is of more immediate appeal to the practical man than either of its forerunners. This is not to infer it is necessarily of greater actual value, but it submits a number of facts that are beyond contention which can be seized upon by the steel foundry practitioner and applied to his instant advantage.

Some of the implications strike heavily at practices that are followed with the blind faith in tradition which has characterized the production of steel castings. The steel founder, and his product, will be the better as the result of the scrapping of worthless traditions and shibboleths. As example, a study of Fig. 2 will show how utterly useless and wasteful it must be to fill up the shrinkage cavities in feed heads long after the castings are poured and completely solidified. That the "plugging" of feed heads may *appear* to produce soundness in a casting at a location which would have shown a pipe or shrinkage cavity is no warrant for the practice. It should, rather, be evidence that the original feed head was of

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insufficient capacity or that provisions were inadequate to insure the proper functioning of the devised amount of feed metal.

"Plugging" of heads may be satisfactory for some castings, but for others which are to be involved in onerous conditions of service the procedure should be discontinued and replaced by ordered, informed, and coherent practice that will result in the production of castings unafflicted with the deficiencies that are inevitably entailed by avoidable inhomogeneities and the stresses that are likely to be associated with the terminus of a temperature gradient such as is the root of a pipe cavity.

With the data before him, as presented by the authors, the practical man can determine whether, or not, in relation to the time which has elapsed, it is advisable—or merely delusive—to add metal to a head which shows a deep shrinkage cavity. Generally speaking, the "plugging" of heads is a waste of money unless there is an absolute assurance that the riser still contains liquid metal immediately before the addition of new, hot, metal is made. Such conditions pertain in properly proportioned heads on large castings and, in consequence, the procedure of repeated feeding is sound and economical in some instances.

Continuing to deal with the data, in its logical application to the functioning of feed heads, we must keep in mind the fundamental fact that steel freezes as a continuously thickening envelope through a considerable proportion of the progress of solidification. It has been shown that, "The velocity of solidification is a constant. That is, at any definite time after pouring the weight of steel solidified * * * *per square inch of mold surface* is the same," and, "The greater the surface area the faster is the rate of skin formation. The differences are, however, small."

Here are implications as to the shape of feed heads or risers. The ideal form of riser is, most probably, a sphere but there are practical difficulties in the way of applying economically such a form of feeder. For the purpose of a practical exposition of the author's data, as applicable to risers, we may take three different forms of approximately identical volumes:

	Size	Capacity Cubic Inches	Surface Area (Sides & Top) Sq. Inches	Surface Area (Sides only) Sq. Inches
A	9 ins. diam. x 10 ins. high......	636	350	285
B	8 ins. x 8 ins. x 10 ins. high....	640	384	320
C	13 ins. x 5 ins. x 10 ins. high....	650	485	420

The surface of the metal in the riser is, if not protected by an insulator, subject to more rapid cooling than is the metal in contact with sand. It is, therefore, reasonable to assess the exposed surface as being in contact with a coolant which immobilizes metal by solidification and, thereby, prevents it functioning as a feeder.

Taking simply the linear solidification, it can readily be seen that the riser of type *C* will be solidified completely (at the first place to "bridge" below the surface cake) while riser type *A* still has a liquid core at least 4 inches in diameter. Further, that the riser type *B* would be solidified throughout while riser *A* still had a liquid center. The foregoing propo-

sition disregards the fact that in the predicated period, the risers would, in practice, be delivering metal to the casting upon which they were placed.

Relating the risers to actual service conditions, where the upper surface is covered with an insulator—preferably of a non-carbonizing nature—and plotting against time the proportion of the riser metal which is immobilized by solidification, it can readily be seen that the riser of circular section is, of the three commonly used types, obviously most efficient as a reservoir of temperature. To function efficiently a riser must be a reservoir of temperature as well as a reservoir of metal simply because solidified metal cannot feed.

The area of contact of metal with coolant prescribes the rate at which metal is immobilised in a feed head and it therefore necessarily follows that as the ratio of area to volume increases the potential efficiency of the riser decreases.

Undoubtedly the primary purposes of the authors was to indicate mold effects in relation to rates of volume change, to set up guide posts in relation to the influence of some elements of design upon the practicability of producing integrally sound castings, and to provide for practical foundrymen some long-needed data to add to the working tools of the craft. I have taken it upon myself to relate these data to the design and functioning of feed heads before proceeding to discuss them in relating to castings.

If we take the data on rate of skin formation of the 6 ins. diameter sphere and the parallelepipeds of equal volume, and consider each one as oeing used as a feed head we may obtain a graphic demonstration of their relative efficiencies. The appended Fig. 15 illustrates the point it is desired to emphasize. From this, it can be seen that in one minute the following amounts of metal have been immobilized and cannot function as feed:

Parallelepiped	1-22/64 in. x 10-5/32 ins. x 8 ins.	27.6 pounds
"	2-1/4 ins. x 6-1/4 ins. x 8 ins.	19.8 pounds
"	3-5/8 ins. x 3-5/8 ins. x 8-5/8 ins.	18.3 pounds
Sphere	6 ins. diameter	13.4 pounds

The thinnest block would, of course, be a ridiculous form to adopt as a feed head, but it is regretfully submitted that it is no uncommon thing to see risers applied which conform closely to the dimensions of the piece 2-1/4 ins. x 6-1/4 ins. x 8 ins.

Projecting the curves, it would appear that complete solidification, and absolute cessation of feeding, would occur approximately at:

1.5	minutes	for	parallelepiped	2-23/64 ins. x 10-5/32 ins. x 8 ins.
2.7	"	"	"	2-1/4 ins. x 6-1/4 ins. x 8 ins.
3.6	"	"	"	3-5/8 ins. x 3-5/8 ins. x 8-5/8 ins.
7.2	"	"	sphere	6 ins. diameter

assuming the original metal contained to be 32 pounds.

While it is desirable to retain heat in a riser as long as possible it is desirable to extract heat as rapidly as is safely practicable from the casting. It follows, therefore, that the shape or form which is most efficient as a riser is precisely the shape or form which will be most difficult to produce as an integrally sound casting.

The authors have evoked their data, necessarily, from castings of simple form and harmonious design and it remains to the operative foundry-

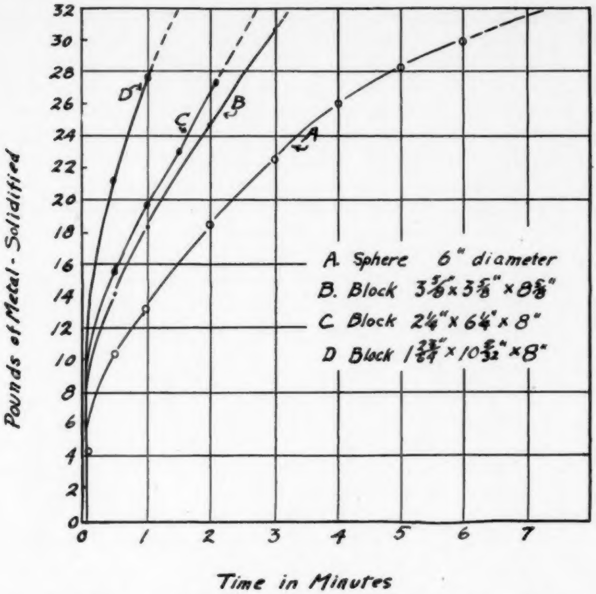

FIG. 15—AMOUNTS OF METAL SOLIDIFIED AT DEFINITE TIME INTERVALS IN PARALLELEPIPEDS AND SPHERES.

man to harness the information for his own advantage. At the same time it must be stated that a great deal of good would also come of the authors' work if designers could be impelled to study it and learn therefrom that isolated pads, bosses and plates in inaccessible places may be a cause of failure by reason of strains inherent at the terminus of a local temperature gradient. Any plea for simplification, or rather rationalization, of design may not properly be assessed as the plaint of an inept industry. Rather it should be considered the frank expression, by informed and competent technicians who are aware of the nature of the material with which they deal, of facts which may not be burked.

The conjoined cylinders which are shown, after bleeding, in Fig. 11 illustrate strikingly two things of considerable import to the founder—namely, metal corner effect and mold corner effect. The examples bled at one minute, and two minutes, after pouring are particularly striking in their implication of acute weakness of metal structure at a mold corner or angle. It is obvious that generous fillets must, in many cases, be considered an essential element of design; yet it is not uncommon to see in the foundry patterns of a shape somewhat similar to what would be produced by joining two such pieces together, small end to small end, making something which looks rather like a dumb-bell. Very little mold resistance will generate rupture at the weakest part of the solid envelope.

The data of the effect of pouring temperature on rate of skin forma-

tion is particularly interesting and although the effect is not as great as some of us would have expected, it is obviously a factor that must be considered in the making of complicated castings. The practical man may have some hesitation in conceding the rectitude of the figures quoted when he sees castings mis-run from metal which appears of adequate temperature, but it must not be forgotten that a good deal of heat is lost to the atmosphere of the mold cavity in addition to that selectively extracted by the mold from metal in transit. It is this selective cooling of metal, as a function of the proportionate metal contact with mold, which makes controlled directional solidification so simple to achieve on many types of castings.

The paper is a remarkably concise summation of what appears to have been a tremendous amount of work. It is worthy of the closest study by all who are interested in either the designing or the making of steel castings, and it might be said also that close study will eliminate some seeming ambiguities of definitions as related to data. The American Foundrymen's Association is fortunate in securing for publication the work of these two investigators who have a peculiarly happy genius for the proper focus of a practical problem. At the same time, it appears proper to applaud the Department which finances the investigation and sanctions promulgation of the accrued data to the benefit of our industry.

MESSRS. BRIGGS AND GEZELIUS (*Written Reply to Written Discussion*): We appreciate Mr. Batty's discussion as we were hoping that someone who is much more familiar with the practical side of steel castings than we are would try to correlate the results that we have presented with shop procedure. Mr. Batty has presented an excellent discussion of feed heads and their rate of solidification. What he has said is to the point and we express our thanks for his valuable aid as we feel that his contribution materially strengthened the practical aspects of the paper.

CHAIRMAN E. W. CAMPION[2]: Will Mr. Gezelius say something about the general significance of the work that you have done and perhaps point out the manner in which you have used some of the information?

MR. GEZELIUS: The mechanics of solidification and rate of skin formation is generally known to all foundrymen, although this is probably the first time that actual data have been presented. Data of this type can probably be used more by a designer than by the foundryman. In the foundry business, most of the difficulties encountered are due to design rather than manipulation in the foundry. We hope that eventually a few of the engineers who design castings, and who have to have figures with which to work, may be able to use it and in that way reduce the labor necessary to produce sound castings.

We intend to go a little further with this study and see if it is not possible to formulate a few general rules of design. Of course, it is impossible to make any rule that will cover all cases but maybe a few general rules would help the engineer to design castings that the foundryman can, with not too much difficulty, produce.

E. H. BALLARD[3]: The thing that appeals to me is that we have the general information correlated. Now if it can be put to use by designing

[2] Bonney Floyd Co., Columbus, O.
[3] General Electric Co., West Lynn, Mass.

engineers, there is no question but that that is the greatest good that can be accomplished by the accumulation of such material. One of the most important things that we have in front of us as steel foundrymen, is to take the information that is gathered together by such painstaking effort as in the case of the data of this paper and put it in the hands of those who can make life more pleasant for those who have to produce steel castings. I think this paper is a very fine contribution.

CHAIRMAN CAMPION: We all can understand very clearly how much our troubles would be eased for us if we could get this information in the hands of the designing engineers and have them use it.

JOHN HOWE HALL[4]: It seems that we should at least express, as Mr. Ballard did, our appreciation of the value and interest of this work that Mr. Briggs and Mr. Gezelius are doing, putting before us in definite terms and in real knowledge a great amount of data, on lines previously only guessed at and speculated upon. The work is of the greatest value and, as it progresses, I feel sure that my successors as Chairman of the Papers Committee of the Steel Foundry Division will wish to secure these contributions yearly, or every other year, as the work is finished up, because it is so valuable to us.

From listening to the presentation, the thing that struck me most was the statement that steel in solidifying does not pass through a mushy stage; that, practically speaking, any given layer of steel solidifies quickly, goes rapidly from liquid to solid. This I admit is a good deal at variance to my own ideas. I wish Mr. Briggs could give us a little more light on just how far that is so.

MR. BRIGGS: Our opinions on fluidity have been obtained through extensive observations of the bleeding of castings, also from the theoretical and practical observations by noted investigators. We trust that no one is confusing fluidity with the so-called mushy stage of solid steel where steel lacks strength. The extremely low strengths and ductilities encountered in cast steel at these high temperatures has been referred to as the mushy state, but since steel can have no strength or ductility until it has solidified it is obvious that this solid phase has no connection to the fluidity on the liquid condition of the steel. It would appear from Mr. Hall's statement that it is his opinion that steel becomes very viscous prior to solidification. We feel that this is not the case for in the 300 odd bleedings we have carried out in various sections at various times there has always been obtained an inner surface of dendrites. In some cases the protruding dendrites are large, in other cases are small, all depending on the degree of superheat of the steel. Castings that have been bled late or near the end of their solidification period show their inner surfaces to be similar to those bled after only a skin has formed. If the steel had been extremely viscous the growing dendrites would have been washed off or filled up as the steel was emptied from the castings, and dribblets of the mushy steel would have remained in the casting. Such conditions however were never encountered. In fact, the steel as it came from the casting always appeared quite liquid.

The solidified dendrites may be very plastic but they are solid material

[4] Taylor Wharton Iron & Steel Co., High Bridge, N. J.

and not a highly viscous liquid. The interstices between the growing dentrites may still be liquid but here also this liquid steel is very fluid as cavities between the dendrites are noticeable in bled castings.

E. J. ASH[5]: In his presentation, Mr. Briggs stated that steel does not pass through a mushy state in freezing. This statement is difficult to subscribe to without some modification since it is contrary to the principles of solidification of solid solutions.

MR. GEZELIUS: The statement that we made was that the volume of steel solidified per square inch of surface area is the same no matter what the shape of the mold may be. In a round riser, there is considerably less surface area than there is in a square riser; therefore, one would expect the amount of steel solidified to be less than it would in a square riser. If that is true, it follows that the percentage of steel solidified is greater in the square riser than it is in a circular one and the circular riser is more efficient.

I am not qualified to speak on the solidification of brass, but we stated with regard to steel that it passed from a liquid to a solid state in a comparatively short time. If it were in a mushy state, it would not be possible to dump out a casting and have large dendrites sticking out in the mass. Those dendrites would hold mushy steel between them. It must be liquid, because it runs out. Many times there are holes that go back between these dendrite formations just like pin points and if the steel were mush, it most certainly would be held there. In other words steel freezes like ice rather than say, as molasses. As the temperature goes down, molasses gradually gets more and more viscous until it finally reaches the point where it will not pour at all. Steel—it is not comparable, of course, but it is qualitatively true—acts more or less like ice and water. It is either liquid or solid.

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[5] Watertown Arsenal, Watertown, Mass.

Relation of the Air Charge to Cupola Operation

By H. V. Crawford,* Schenectady, N. Y.

Abstract

In this paper, the author discusses the various reactions that take place within the cupola and shows how it is best to operate such a furnace. He divides the cupola into zones and explains the functions of each. He also explains the reactions that should take place within each zone and how improper control of air supply, coke and iron charges influence the thermal efficiency and consequently the melting efficiency of such a unit.

1. The complete function of the cupola is the generation of the proper amount of heat by combination of certain amounts of oxygen and carbon, so that the metal charge will be melted and superheated to such a temperature that the metals of different analyses in the charge will mix properly, that the resulting iron will have the calculated chemical analysis and physical characteristics and that a minimum amount of slag and absorbed gases will be contained in the iron when made into castings. These results must be obtained with the proper melting speed and the minimum amounts of air and coke.

2. Considerable attention has been given to the use of coke but, until recently, air generally has been considered the item of least importance. Air is equally as important as coke, since the oxygen in the air combines chemically with the carbon of the coke to produce heat, in accordance with the relative amounts of oxygen and carbon present and the prevailing temperature.

3. *Transactions*, American Foundrymen's Association, vol. 40, pp. 483-490, 1933, contains a report on "Recommendations for Cupola Operation," made by a subcommittee of the A.F.A. Gray Iron Division Committee on Gray Iron Castings, after several years' work. Under the heading "Blast," the following state-

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* Industrial Department, General Electric Co.

Note: This paper was presented at one of the Cast Iron Shop Operations Course sessions at the 1935 Convention of A.F.A. in Toronto, Canada.

ment is made: "The column of blast air, or better, the actual weight of oxygen charged, is the most important consideration in the operation of the cupola." This is true, because, once the cupola is filled with coke and iron, the operating results depend entirely upon the air (oxygen) supplied.

4. The operation of the cupola is largely a process of combustion and it is essential that the general principles of combustion be understood if the best and most consistent results are to be realized.

5. In the operation of the cupola, six well known laws pertaining to combustion are involved. These are shown in Table 1. The first four involve the combination of carbon and oxygen and the last two, of hydrogen and oxygen. The hydrogen and oxygen reactions are involved on account of the moisture (H_2O) in the air introduced into the cupola.

6. In all six equations given, elements enter into a direct combination to form compounds and a definite amount of heat is either evolved or absorbed. The amount of heat per lb. of the element involved is given with each equation.

7. It is necessary to have the proper temperature conditions before the carbon and the oxygen will unite. In the cupola, it is necessary to ignite the coke in the bed by burning wood or other fuel. As soon as the coke settles, it is at such a temperature that natural draft will cause it to continue to burn and become incan-

Table 1

CUPOLA REACTIONS SHOWING HEAT GENERATED OR ABSORBED

(1) $C + O_2 = CO_2 + 14{,}550$ B.t.u per lb. of carbon burned, or
2.667 lb. oxygen + 1.0 lb. carbon = 3.667 lb. CO_2 + 14,550 B.t.u

(2) $2C + O_2 = 2CO + 4{,}350$ B.t.u per lb. of carbon burned, or
1.333 lb. oxygen + 1.0 lb. carbon = 2.333 lb. CO + 4,350 B.t.u.

(3) $C + CO_2 = 2CO - 5{,}850$ B.t.u. per lb. of carbon burned, or
3.667 lb. CO_2 + 1.0 lb. carbon = 4.667 lb. CO — 5,850 B.t.u.

(4) $2CO + O_2 = 2CO_2 + 10{,}200$ B.t.u. per lb. of carbon burned, or
1.333 lb. oxygen + 2.333 lb. of CO (which contains 1.0 lb. of carbon) = 3.667 lb. CO_2 + 10,200 B.t.u.

(5) $H_2O + C = CO + H_2 - 5{,}900$ B.t.u. per lb. of carbon burned, or
1.5 lb. H_2O + 1.0 lb. carbon = 2.333 lb. CO + 0.1668 lb. H_2 — 5,900 B.t.u.

(6) $2H + O = H_2O + 61{,}500$ B.t.u. per lb. of H_2 burned, or
1.0 lb. H_2 + 8.0 lb. O_2 = 9.0 lb. H_2O + 61,500 B.t.u.

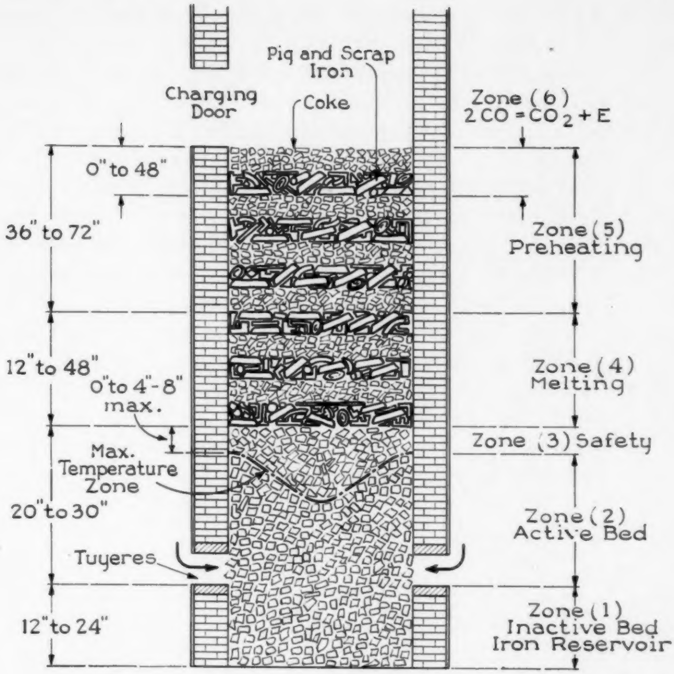

FIG. 1—CROSS-SECTION OF CHARGED CUPOLA SHOWING VARIOUS ZONES.

descent throughout. It is then ready to burn at a certain rate as soon as the air is introduced.

8. Fig. 1 shows the cupola divided into six zones. The body of coke under the first charge of iron is called the bed and takes in the first three zones.

9. Zone 1 extends from the sand bottom up to the bottom of the tuyeres and serves as a reservoir for the molten iron. As soon as the bed is properly burned, the tap hole and any other holes flush with the top of the sand bottom, are closed and there is no way left for air to get into this zone. Therefore, no more of the coke in this zone will be burned. This zone can then be called the inactive part of the bed and, as soon as melting is started, it is out of the picture as far as combustion or any con-

trol of the melting operation is concerned. Ordinarily its depth will vary from 10 to 24 in.

10. Zone 2 is that part of the bed extending from the bottom plate of the tuyeres, or the top of the reservoir, to the point in the bed where all of the oxygen of the air has combined with carbon in the coke. This can be called the active bed and it varies in height with the amount of air supplied. If there is not enough coke in this zone, or the amount of air is too great, the metal charges too large, the scrap too heavy, or the coke charges too small, it can be readily appreciated that melting iron will get into this zone and excessive oxidation will take place.

11. The air charge is the only material that can be varied under any of these conditions, and simply reducing it will eliminate the difficulty. The melting rate will be lowered but the iron melted will be unoxidized and should be hot. If there is no way of varying the amount of air, oxidation will continue until a booster charge of coke can reach the bed.

ZONE OF HIGHEST TEMPERATURE

12. Since all of the oxygen of the air is used up in zone 2 and a maximum amount of carbon is burned to CO_2 with a minimum to CO, it must incorporate the plane or zone of highest temperature. Ordinarily the amount of oxygen supplied should be such that zone 2 will be from 20 to 30 in. high. However, due to low amounts of air in some cases, it may be as low as 10 in. while on the other hand, with excess air, it may be as high as 60 in.

13. Zone 3 constitutes the upper part of the bed and, as the coke in the bed is consumed, the coke in this zone gradually sinks into and becomes a part of zone 2. It should at all times contain enough coke to keep zone 2 full of coke, in order that the iron, which is immediately above zone 3, cannot get into zone 2, where it would come in contact with free oxygen. Zone 3, therefore, can be considered as the safety zone.

14. When the cupola is started, zone 3 should extend above the top of zone 2 a distance equivalent to the thickness of one of the coke charges when it reaches this zone. This is correct only in case the amount of coke in a charge is sufficient to keep zone 2 full of coke until the first charge of iron is melted. The amount of coke in zone 3 is gradually reduced as the oxygen of the air combines with the carbon of the coke in zone 2 and forms CO_2. This CO_2 then combines with more carbon in both zones 2 and 3.

Just as the last of the coke in zone 3 sinks into zone 2, the last of the iron in the first iron charge should be melted and the next charge of coke should bring zone 3 up to its original height. This should be the procedure throughout the entire heat and is based on the amount of oxygen, as well as iron and coke, being kept constant.

15. If the amount of oxygen is such that it is all gone at a point 30 in. above the tuyeres, zone 2 will be 30 in. high. If the bed is made so that the first iron is 60 in. above the tuyeres, then zone 3 must be 30 in. deep. With so much coke in zone 3, each pound of carbon burning to CO_2 in zone 2 will develop just enough CO_2 to pick up another pound of carbon in zone 3 and the heat available will be only 8,700 B.t.u. for 2 lb. of carbon consumed. This is equivalent to 4,350 B.t.u. per lb. as compared to a maximum of 14,550 B.t.u. per lb., or the minimum combustion efficiency of 29.9 per cent.

16. Zone 3 is necessary as a safety zone, to prevent excessive oxidation. However, it is the zone where heat is absorbed and coke is wasted by the reaction

$$CO_2 + C = 2CO - 5{,}850 \text{ B.t.u. per lb. of carbon.}$$

It should, therefore, be as near the correct depth as possible. The zone of highest temperature is at the top of zone 2 and immediately above this point the temperature starts to drop. Therefore, the thinner zone 3, the nearer the iron will be to this zone of highest temperature and also the less heat absorbed between this point and the iron.

Ideal Conditions

17. For ideal conditions, zone 3 should contain a maximum of one layer of coke and the weight and thickness would depend on the size of the coke. The weight of the iron charges would then have to be such that they would be completely melted when zone 3 became a minimum or zero. The size of the largest pieces of iron in the iron charges and the nature of the mix then determines the maximum depth of zone 3. Since the coke in zone 3 comes from the coke charges between the iron charges, the size of the coke charges depends on the size of the iron charges as well as the amount of coke burned to CO before the coke charges reach zone 3.

18. In a cupola lined to 54 in., coke will weigh about 33.5 lb. per in. of height so that if the coke is reduced in size to about

4 in. when it reaches zone 3, one layer of coke will weigh 134 lb. Assuming, at a ratio of 10 to 1 in the charges, that 25 per cent of the coke in the charges is burned to CO before the charges reach zone 3, 178 lb. of coke and 1,780 lb. of iron would be the weight of the charges. Zone 3 then should vary from zero to a maximum of 4 to 8 in. as compared to as much as 30 in. in some cases.

19. The first iron is immediately above zone 3 so that zone 4 must be the melting zone. The first iron to melt will then be at the top of zone 3 or the bottom of zone 4 and as the coke in zones 2 or 3 is consumed, the bottom of zone 4 drops down into zone 3. The nearer the iron in zone 4 gets to the bottom of zone 3, the nearer it gets to the region of highest temperature in zone 2. Therefore, the thinner zone 3, the higher the temperature in which the iron will be melting, and the hotter the iron.

20. The smaller the amount of coke in zone 3 and the coke charges, the greater the iron to coke ratio in the melting zone and consequently the more iron melting in the higher temperature zone, also the less coke to absorb heat and the less wasted in CO formation. After the cupola has operated for a certain length of time, iron will be melting in two or more of the iron charges or as high up in the cupola as the melting temperature prevails, providing the iron is thoroughly preheated in zone 5 or the preheating zone.

MAXIMUM TEMPERATURES

21. Belden's tests indicated a maximum temperature of over 3100 degrees Fahr. Therefore, as the iron in the lowest iron charge approaches the top of zone 2, it can be melting in a temperature of 3100 degrees Fahr. whereas at the top of zone 4, it will be melting in a temperature of 2200 to 2300 degrees Fahr. The iron melted at 2200 degrees Fahr. will pick up some heat as it drops through the higher temperature zones but for a maximum temperature of the iron over the spout, a maximum amount of iron should melt in the high temperature zone.

22. According to Belden, the top of zone 2 is "*V*" or "*U*" shaped so that the iron in the center of the first charge is farther away from the zone of highest temperature. Consequently this iron melts in a lower temperature zone than the iron along the sides. As melting proceeds, with the coke burning faster and the iron melting faster along the walls, the bottom of zone 4 can be in the form of an inverted "*V*" or "*U*." A ball-shaped zone of

lower temperature and lower melting speed will then be formed in the center. Proper charging of air, iron and coke will reduce this zone to a relatively small area. The depth and shape of zone 4, therefore, depends on the amount of air used and the amount of coke in zones 2 and 3.

23. The zone of maximum burning of the lining should always be at the top of zone 2 and, therefore, its distance above the tuyeres depends on the amount of oxygen used. If the oxygen is the same every day and all during the heat and the cupola is lined up the same way, this zone will always be at the same place. If the oxygen is increased and too much is supplied for the amount of coke in the bed and the charges, zone 4 will sink below zone 3 and down into zone 2. Zone 3 will be eliminated and zones 2 and 4 and the zones of highest temperature and maximum burning of the lining will coincide. Some of the oxygen of the air then reaches the melting iron and combines with the elements in the iron and excessive oxidation takes place.

24. The maximum depth of zone 4 should correspond to the thickness of one iron charge for ideal conditions of high temperature, minimum carbon and sulphur pick, and minimum coke consumption. This, however, is impossible as melting will take place in two or more charges at the same time. The actual depth depends on the amount of heat available, the speed of the heat bearing gases, the ability of the iron to pick up heat, and the amount of coke between the iron charges. It probably varies from 12 to 48 in. If zone 3 is not too deep, all through zone 4, CO_2 will combine with carbon in accordance with reaction (3), Table 1, and CO will be formed, as the temperature will be well above 1800 degrees Fahr.

25. The iron in the charges starts to absorb heat from the hot gases and the lining just as soon as it is thrown into the cupola at the charging door. Zone 5 or the preheating zone, therefore, extends from the top of zone 4 to the charging door and its actual depth depends on the height of the charging door above the tuyeres. The charging door should, therefore, be just high enough so that the iron will gradually increase in temperature in zone 5 and will be at its melting point when it reaches zone 4. There are no advantages in having the charging door any higher but there are a number of disadvantages such as increased heat loss by radiation, higher wind box pressure, etc.

26. Carbon monoxide (*CO*) will form in zone 5 in accordance with reaction (3), Table 1, as high up as CO_2 is available and the

rate of formation will be maximum when the amount of CO_2 is a maximum and the temperature is 1800 degrees Fahr. and higher. This all depends on the amount of CO_2 formed and heat developed in zone 2 which, in turn, depends on the amount of air used. It also depends on the height of zone 3 as there may be enough coke in this zone to use up all the CO_2 before any of it can reach zone 5. However, under these conditions, the results would be very poor until the bed burned down and then CO would start to form in zone 5. The best results are obtained when the CO formation in each zone is a minimum and when the largest part of the total amount formed in all zones is formed in zone 5.

27. As the temperature in zone 5 decreases from 1800 degrees Fahr., reaction (3), Table 1, reverses very rapidly and at 950 degrees Fahr., this breaking down of the CO into CO_2+C is almost quantitative. Therefore, it is possible to consider a sixth zone in the cupola which will extend from a point in the upper part of zone 5 where the temperature is 950 degrees Fahr. up to the charging door. Ordinarily, the method of operating the cupola is such that there is very little distance or time in which the CO can revert to CO_2+C so that very little benefit can be derived in this case. Also under these conditions there is so much more heat than required to bring the iron up to melting temperature that a large amount is wasted. There is, therefore, no reason for increasing the amount of heat by endeavoring to promote the breaking down of CO into CO_2+C by increasing the height of the charging door. However, in those cases where high iron temperatures with high iron to coke ratios are secured, zone 6 plays an important part.

28. In these cases, low beds and low air charges are used and all of the zones contain less coke. Therefore, the cupola will hold more iron charges and it is not necessary to increase the height of the charging door as long as it is 12 to 15 ft. above the bottom doors.

STACK ANALYSES

29. The reverting of CO to CO_2 affects the relative amount of CO_2 and CO in the gas at the charging door. Therefore, in taking stack analyses, this percentage will not be correct as far as the bed is concerned. In some cases, it may be a good indication of whether or not the bed is too high. However, it is possible for the bed to be high enough so that all of the CO_2 formed in the bed will be converted into CO. Then some of this CO reverts

Table 2

CONVENIENT FORM FOR CALCULATING CUPOLA DATA

Name__________ Location__________ Date__________

		1	2	3	4	5	6
1	Cupola inside lining diam. (inches)......	67–72	67–72				
2	Temp. °F. iron at spout................	2800	2800				
3	Ratio (less bed)......................	10:1	6.7:1				
4	Height of bed above tuyeres (inches)...	20 to 30	High				
5	Pounds of coke in bed (4)..............	1000 to 1500					
6	Tons of iron per hour..................	14	14				
7	Pounds of iron per minute..............	467	467				
8	Pounds of coke per minute..............	46.7	70				
9	Pounds of carbon per minute 0.90 x (8)..	42	63				
10	Per cent of carbon to CO_2.............	75	50				
11	Pounds carbon to CO_2 (10) x (9).........	31.5	31.5				
12	Pounds carbon to CO (9)–(11)..........	10.5	31.5				
13	Pounds air (actual)....................	383	383				
14	Pounds air theo. $\frac{2.667}{0.231}$ or 11.545 x (11)...	364	364				
15	Pounds O_2 per minute, 0.231 x (14).......	84	84				
16	B.T.U. perfect comb., 14,550 x (9).......	611,100	916,650				
17	B.T.U. evolved with (14) or 14,550 x (11)	458,325	458,325				
18	B.T.U. absorbed, 5850 x (12)...........	61,425	184,275				
19	B.T.U. available (17)–(18)............	396,900	274,050				
20	B.T.U. required, B.T.U. per lb. x (7)....	272,261	272,261				
21	Thermal eff. (20) ÷ (16) per cent........	44.5	29.6				
22	Combustion eff. (19) ÷ (16) per cent.....	64.9	29.96				
23	Ratio (19) to (20)......................	1.46	1.01				

back to CO_2 in zone 6 so that the stack analysis might show twice as much CO as CO_2. This ordinarily would indicate that twice as much coke was burned to CO as to CO_2 in the bed, whereas we know that one pound of coke burned in the bed will only form enough CO_2 to burn another pound of carbon to CO. The amount of carbon burned to CO cannot be greater than the amount burned to CO_2, with CO_2 being formed first.

30. Zone 5 probably varies from 36 to 72 in. in height, while zone 6, which is the upper part of zone 5, may be from 0 to 48 in. deep.

31. There is no question but that the amount of air or oxygen governs the depth of the various zones and it, therefore, constitutes the very definite control lever of the cupola melting process and governs the quality and cost of the iron running over the spout.

32. Combustion in the cupola can be controlled very definitely by proper control of the air. If the air is supplied so that it is possible to know just how many pounds of oxygen have been introduced into the cupola, and the charging floor record indicates the pounds of coke of a certain carbon content charged, it will be known definitely how many pounds of carbon have been burned with so many pounds of oxygen. In other words, in place of working from the coke end, as has been the custom until recently, it is now considered that the control of the melting operation belongs properly to the air and on this basis very definite calculations can be made. A convenient form for making these calculations is shown in Table 2 and it is self-explanatory.

Adding Ferroalloys in the Cupola

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Abstract

The use of briquetted ferroalloys for cupola mixtures was first developed in Europe about the time of the World War. This method has made considerable stride in this country in the past few years. The field of use is described and the authors present several typical mixtures for various classes of castings. Physical properties of irons from these mixtures are listed. An advantage in the use of briquetted alloys is stated to be that of carrying additional amounts of scrap in the mixture.

1. The idea of briquetting ferroalloys for cupola use was first developed in Europe about the time of the World War, when it was difficult to obtain the desired raw materials. Excessive losses from oxidation of the loose alloy resulted in efforts to protect the alloy from oxidation while passing through the cupola. After tests showed better recovery from alloys charged in steel cylinders, work was done on binding the crushed alloy with cement. Progress was also made towards the successful briquetting of cast iron and steel borings and turnings.

2. Although there have been many references to the use of briquetted ferroalloys in the metallurgical literature of recent years, there have been few articles devoted entirely to this subject.

3. Knowledge of the properties and proper applications of ferroalloy briquets has, however, made great strides during the past few years. The briquets used today are made of crushed ferroalloy with a binder of suitable cement. The alloys available in this form include silicon, manganese, chromium, and certain special alloy combinations.

Field of Use

4. Briquets are used extensively for high-strength or alloyed irons, or where it is desirable to increase the percentage of scrap

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Note: This paper was presented at a Cast Iron Shop course session at the 1935 Convention of A.F.A. in Toronto, Canada.

in the charge. Many foundries run all-scrap heats, adjusting the composition of their iron with briquetted alloys.

5. Briquets were developed especially for the cupola, and have proved adaptable to the special melting methods now used. They are being used in duplexing with the cupola and air-furnace,

FIG. 1—CHARGING BRIQUETS IN A SMALL CUPOLA.

FIG. 2—POSITION OF CUPOLA CHARGES SHOWING SILICON AND CHROMIUM BRIQUETS.

and with the cupola and electric furnace, and can be employed when duplexing from cupola to rotary furnace or Bessemer converter.

6. In practice, briquets are charged on the coke, as near the center of the cupola as possible. They are charged either by hand, as shown in Fig. 1, or by bucket. When charged by bucket, it is advisable to put the briquets in the bottom of the bucket so that they will be in the right position when dumped into the cupola.

Fig. 2 shows a charge of steel scrap, pig iron, and silicon and chrome briquets ready for charging.

TYPICAL MIXTURES

7. Briquets are used in a great many different mixtures for all types of iron. There are, however, certain kinds of mixtures which are typical of the majority of briquet applications. These will be taken up in some detail in the following sections.

8. By far the greatest part of all iron castings made are ordinary gray iron with moderate strength and good machinability. This is not in any sense a special or a high-test iron. It is a good quality gray iron, suitable for many diverse castings, and is the type produced by small foundries who must have one good all-around iron for general work.

Table 1

TYPICAL BRIQUET MIXTURE†

Per Cent	Lbs. Metal Charge	Material	Silicon %	Silicon Lbs.	Manganese %	Manganese Lbs.
25.00	500.	Pig Iron	2.00	10.00	.80	4.00
40.00	800.	Remelt	2.35	18.80	.63	5.04
28.65	573.	Cast Scrap	2.00	11.46	.60	3.44
5.00	100.	Steel Scrap	0.10	.10	.50	0.50
1.20	24.	Silicon Briquets *		11.00	...	.....
.15	3.	Manganese " **		.50	...	2.00
100.00	2000.			51.86		14.98

Silicon charged. 2.59 per cent.. Manganese charged. 0.75 per cent.
* 11 Silicon briquets—1 lb. silicon in each.
** 1 Manganese briquet—2 lbs. manganese and ½ lb. silicon in each.
Note: For heat resistant mixture of 1 per cent Cr., add 11 chrome briquets to above mixture.

9. A typical mixture for this sort of iron is given in Table 1. Charged in at 2.59 per cent silicon and 0.75 per cent manganese, it will come out at about 2.35 per cent silicon, 0.64 per cent manganese, and 3.30 per cent carbon.

10. This iron will have around 30,000 lbs. per sq. in. tensile strength and good machinability. On the 1.2 in. round bar, the Brinell hardness will be around 192. Irons of this type are suitable for valves and pipe fittings, medium machinery castings,

† In connection with this and remaining tables some explanations are desirable.

For the sake of accuracy, the weights of briquets are calculated as the weight of metal contained, as follows:

Each silicon briquet (of this size) weighs 2½ lbs. gross, and contains 1 lb. of silicon metal or approximately 2.2 lbs. of ferrosilicon.

Each manganese briquet weighs 3½ lbs. gross, and contains 2 lbs. manganese metal and ½ lb. silicon metal or approximately 3.1 lbs. of the ferroalloy.

Each chromium briquet weighs 3⅝ lbs. gross, and contains 2 lbs. of chromium, or 3 lbs. of the ferroalloy.

pump casings, farm machinery, enamelled ware, and a general line of medium section castings.

11. This briquet mixture can be adjusted to meet special requirements. If it is necessary to make a heat-resistant iron for a particular job, the only change in the mixture cited in Table 1 is to add eleven ferrochrome briquets, which will give an iron of approximately one per cent chromium.

Table 2

HIGH STRENGTH MIXTURE

Per Cent	Lbs. Metal Charge	Material	Silicon %	Silicon Lbs.	Manganese %	Manganese Lbs.
15.00	300.	Pig Iron	2.50	7.50	.90	2.70
35.00	700.	Remelt	2.00	14.00	.75	5.25
18.15	363.	Cast Scrap	2.00	7.26	.60	2.18
30.00	600.	Steel Scrap	0.10	0.60	.50	3.00
1.55	31.	Silicon Briquets *		14.00	...	.....
.30	6.	Manganese " **		1.00	...	4.00
100.00	2000.			44.36		17.1

Silicon charged 2.22 per cent.. Manganese charged. .86 per cent.
* 14 Silicon briquets—1 lb. silicon in each.
** 2 Manganese briquets—2 lbs. manganese and ½ lb. silicon in each.

12. For a close-grained high-strength iron, the mixture given in Table 2 is frequently used. This, like the mixture in Table 1, is really a base iron, and can be adjusted according to the requirements of the job. Alloys such as chromium, nickel, molybdenum, or titanium may be added to this base mixture either through the cupola or in the ladle.

13. The type of iron represented by the base mixture shown

Table 3

LOW CHROMIUM BRIQUET MIXTURE

Per Cent	Lbs. Metal Charge	Material	Silicon %	Silicon Lbs.	Manganese %	Manganese Lbs.	Chromium Lbs.
30.00	600.	Pig Iron	2.75	16.50	.80	4.80	.....
35.00	700.	Remelt	2.20	15.40	.65	4.55	.....
23.05	461.	Cast Scrap	2.00	9.22	.60	2.77	.....
10.00	200.	Steel Scrap	0.10	0.20	.50	1.00	.....
.75	15.	Silicon Briquets *	....	7.00	...	.....	.....
1.05	21.	Chrome " **	....	.....	...	.....	14.00
.15	3.	Manganese " ***	....	0.50	.....	2.00	.....
100.00	2000.			48.82		15.12	14.00

Silicon charged 2.44 per cent.. Manganese charged. .76 per cent. Chromium charged. .70 per cent.
* 7 Silicon briquets—1 lb. silicon in each.
** 7 Chromium briquets—2 lbs. chromium in each.
*** 1 Manganese briquet—2 lbs. manganese and ½ lb. silicon in each.

in Table 2 is suitable for such work as pulley castings, pressure castings, and automotive work. The composition is usually around 2.00 per cent silicon, 0.75 per cent manganese, and 3.00 per cent carbon. A tensile strength of around 40,000 lbs. per sq. in. may be expected.

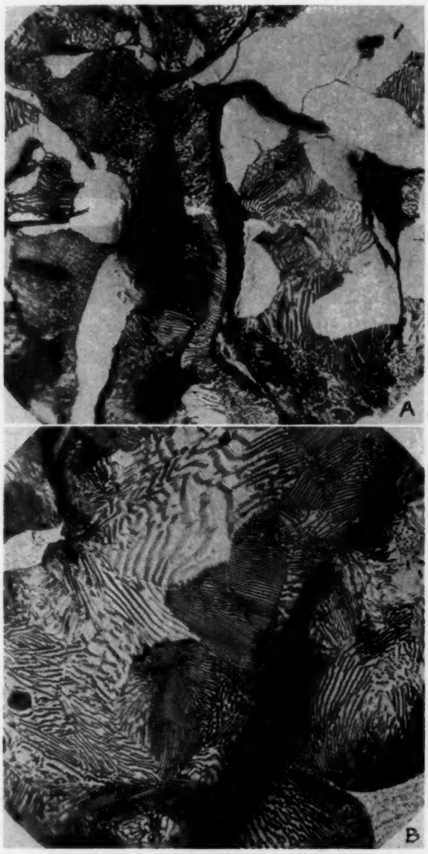

FIG. 3—MICROGRAPHS OF CAST IRON x 1500 (REDUCED APPROXIMATELY 50 PER CENT IN PRINTING) (R. G. GUTHRIE AND L. F. LOTTIER)—*A*, UPPER, UNALLOYED CAST IRON; *B*, LOWER, ALLOYED CAST IRON.

14. Table 3 illustrates a medium strength mixture with a small percentage of chromium. This is frequently used for castings in which additional resistance to heat or wear is required.

It is also used for castings of heavy section where a metal which is close grained throughout the section is desirable.

WEAR RESISTANCE APPLICATION

15. An illustration of a good application of a low-chromium cast iron made in the cupola with briquets is shown in Fig. 3*A* and *B*. Fig. 3*A* shows the microstructure of the unalloyed cast iron which was not meeting service requirements. It was not standing up under the metal-to-metal wear to which it was exposed. As is evident, the structure of this iron consists of coarse graphite flakes in a largely ferritic matrix, with some pearlite.

16. To meet the service requirements, it was advisable to change the coarse ferritic structure to a pearlitic matrix with fine graphite. Dropping the carbon and silicon to obtain pearlite was not practical, because some of the castings were of uneven section and they all had to be machined. Therefore, as this was a production job run through the cupola, the analysis was changed to include 0.40 to 0.50 per cent chromium and 1.00 per cent of either copper or nickel. Fig. 3*B* shows the iron resulting from this alloy composition. The ferrite has been eliminated, giving a completely pearlitic matrix. Photomicrographs at lower magnification show that the size of the graphite was greatly decreased. As was expected, this iron is giving much better service than the one shown in Fig. 3*A*.

17. The mixture given in Table 4 produces an iron containing about 15 per cent chromium, with around 1.7 per cent silicon and 0.67 per cent manganese. This type of iron resists both growth and oxidation, and is used for resistance to heat up to 1600 degrees Fahr. It is used especially for castings of heavy

Table 4

HIGH CHROMIUM CAST IRON MIXTURE

Per Cent	Lbs. Metal Charge	Material	Silicon %	Silicon Lbs.	Manganese %	Manganese Lbs.	Chromium Lbs.
34.60	692.	Machinery Scrap	2.00	13.84	.60	4.15	.....
37.00	740.	Steel Scrap	0.10	.74	.50	3.70	.....
25.50	510.	Chrome Briquets*	....	.....	...	.....	340
2.30	46.	Silicon " **	....	21.00	...	.....	.....
.60	12.	Manganese ***	....	2.00	...	8.00	.....
100.00	2000.			37.58		15.85	340

Silicon charged 1.88 per cent.. Manganese charged . .79 per cent. Chromium charged 17.00 per cent.

*170 Chrome briquets—2 lbs. chromium in each.

** 21 Silicon briquets—1 lb. silicon in each.

*** 4 Manganese briquets—2 lbs. manganese and ½ lb. silicon in each.

uniform section which are not exposed to much impact, such as stoker links and some types of grate bars.

18. Fig. 4 shows the condition of (*a*) an ordinary white iron stoker link after three months' service; (*b*) a 15 per cent chromium cast iron, made in the cupola with chrome briquets, after two years of the same service; and (*c*) a new casting. The alloyed stoker link shows practically no oxidation or scaling after

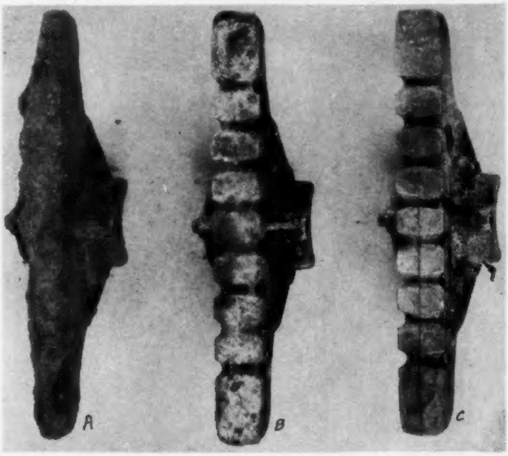

Fig. 4—Stoker Links, (A) Ordinary White Iron after 3 Months Service; (B) Fifteen Per Cent Chromium Iron after 2 Years Service; and (C) New Casting Shown for Comparison.

two years' service, while the unalloyed link was useless after three months.

19. This iron, which is typical of high-chromium cupola irons, calls for changes in foundry practice. Heavier gates and risers are required, somewhere intermediate between gray iron and steel practice. In pouring, this iron presents a deceptive appearance because of the film which forms over the surface. The presence of this film does not mean that the iron is cold, as light sections can be poured readily.

20. It is possible to run even a few charges of alloyed iron. When a few special briquet charges are required, they should be either at the first or the last of the day's run. The writers would advise running the special iron at the end of the day. All the regular iron should be run out of the cupola, and the bed rebuilt to its original height, before charging the alloy mixture.

21. In Table 5 is given a typical mixture for an all-scrap charge. All-scrap mixtures are used primarily to reduce costs, although all-steel charges are also run to get a low carbon. A factor which may cause trouble in running all-scrap heats is that the sulphur may get too high, when there is a large proportion of remelt. To offset the high sulphur, manganese is often run rather high, and desulphurizing is also often employed.

22. The 100 per cent scrap mixtures have been looked on with suspicion for many years, and have been blamed for bad

Table 5

ALL SCRAP MIXTURE

Per Cent	Lbs. Metal Charge	Material	Silicon %	Silicon Lbs.	Manganese %	Manganese Lbs.
40.00	800.	Remelt	2.32	18.56	.70	5.60
53.60	1072.	Cast Scrap	2.00	21.44	.60	6.43
5.00	100.	Steel Scrap	0.10	0.10	.50	0.50
1.10	22.	Silicon Briquets *		10.00	...	.....
.30	6.	Manganese " **		1.00	...	4.00
100.00	2000			51.10		16.53

Silicon charged 2.56 per cent.. Manganese charged. .83 per cent.
* 10 Silicon briquets—1 lb. silicon in each.
** 2 Manganese briquets—2 lbs. manganese and ½ lb. silicon in each.

iron. It is obvious that when burned material, loose borings, sash weights, etc., are charged in the cupola indiscriminately, and when desulphurization is not attempted and no regular analyses are taken, then bad iron will result. However, when clean, graded, properly sized scrap is used and modern methods of metallurgical control are employed, the all-scrap mixture has a definite place in the foundry.

23. The authors would like to voice their personal opinion on the economic side of the use of scrap in foundry mixtures. There is a certain amount of scrap made every day in the foundry industry, and it is economically necessary that this scrap be remelted. A certain proportion of all the new castings is completely lost, either through rust or other natural causes; but the balance of such castings will eventually come back in the form of scrap for remelting. The amount of pig iron necessary to make up the difference between the tonnage of scrap available and the tons of new castings needed will vary from time to time, but there will always be an equilibrium between the amount of scrap available, its price, and the amount of pig iron used in the mixtures. The briquets simply offer a more accurate and better way of utilizing whatever tonnage of scrap is available.

Fifteen Years of Foundry Apprenticeship at the Falk Corporation

By V. J. Hydar*, Milwaukee, Wis.

Abstract

The author reviews the success of an apprentice training program at the Falk Corp., Milwaukee, explaining how many boys have been trained by that company since the institution of the program 15 years ago, how many have completed the courses, the number of apprentices that have graduated, the number remaining with the company and tells some of the positions both within the company and in outside shops, that graduate apprentices occupy.

1. There is one indisputable fact which industry must face now or in the very near future and that is the ever increasing shortage of skilled labor in practically all occupations. The foundry is no exception in this matter, sadly enough, despite the fact that many employers had pushed their apprenticeship programs to the limit for a number of years prior to the depression. Indeed, a few have continued their training programs, and even augmented them, throughout the last five or six years in the face of uncertainty and loss of revenues.

Shortage Imminent

2. This shortage of skilled help is exemplified in the recent experience of a well-known mid-western steel foundry, which, on reopening its Chicago plant, interviewed more than 600 applicants for work, and out of these, was able to glean only a total of 28 who could qualify as skilled molders and coremakers. There is only one answer to the problem and that is reasonable participation by all employers in good, sound apprenticeship. The majority have hesitated in this matter even during the days of plentiful work, apparently, because the results of such an undertaking seemed to them too uncertain and too remote. Perhaps, an outline of some of the benefits enjoyed by the Falk Corporation through

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* Personnel Manager, Falk Corporation.

Note: This paper was presented at the session on Apprentice Training at the 1935 Convention of A.F.A. in Toronto, Canada.

its apprenticeship program will be indicative of what any employer can expect from a similar enterprise.

FIFTEEN YEARS OPERATION

3. It is now a little over 15 years since the Falk Corporation launched its present system of apprenticeship. Not that there had not been apprentices in the Falk plant prior to that time, but training had been carried on in a desultory manner. The pattern shop had produced occasional journeyman patternmakers for years, and there had been a few, very infrequent apprentices in the machine shop and the foundry. However, each department worked independently of the others in this matter and none of them was doing the job that should have been done, particularly with respect to the number of trainees in process.

4. The first apprentice under the present system was engaged in 1920, and the first three or four years after that the number of apprentices on the payroll grew apace. At one time, there were as many as 180 apprentices distributed among the four major departments in which training was in progress. Of these departments, including the foundry, machine shop, pattern shop and drafting room, the foundry accounted for the largest individual share of apprentices.

5. As time went on, however, and the first flush of excitement over the program subsided, the apprentice department viewed its need for candidates from the angle of apprentice and journeyman turnover and established a quota of apprentices for each department. It was found that a total of about 130 boys under contract was sufficient to take care of the normal needs of the company.

APPRENTICE QUOTAS

6. While the method of arriving at this quota is simple enough in its operation, the business of explaining it is rather lengthy and beyond the scope of this discussion. However, briefly, the number of apprentices engaged and maintained must be calculated so as to produce graduates in the same number as skilled mechanics leaving the employ of the company in any year. Adjustments must be made, of course, for the skilled mechanics engaged from the outside, the percentage of apprentices dropping out in total, the percentage of apprentices dropping out in the first year

and again in the second year, and the proportion of three year and four year apprentices on the payroll.

7. Arrival at our quota was based on the average figures as obtained from the records of our plant for some years prior to the calculations. A formula was developed which can be applied to anyone's case, regardless of whether he operates a foundry or a bakery, a textile mill or a machine shop, so long as the training of skilled help is one of his problems.

8. In reviewing the figures which are about to be presented, it must be kept in mind that, although 15 years have elapsed since the engaging of the first apprentices, there was a growing period of some years during which no apprentice graduates were produced. On the other hand, there has been a long period during the depression in which graduations have been infrequent. Accordingly, the number of graduates has been materially diminished and is really representative of what is more nearly a 9 or 10 year normal period. However, the individual progress of many Falk foundry graduates has been steadily upward through this period and is indicative of the desirability of apprentice training from the standpoint of both the men and the employer through good times and bad.

APPRENTICES ENGAGED

9. During the 15 years under discussion, there have been, in all, 773 young men engaged for one form or other of apprenticeship with the Falk Corporation. Out of this number, 363 were given contracts after having served their probationary periods. These figures include present apprentices, about 58 in number.

GRADUATES

10. To date, there have been 265 graduates and adding, say 50 potential graduates out of the present list of apprentices, the total is brought to 315 or 40.1 per cent of the total engaged and 85.4 per cent of those granted contracts.

11. At this point, reference must be made to the improved conditions of the past 10 years. On the basis of this more recent experience, the percentage of failures has been very materially lower because of the more careful selection of candidates. Since 1925, the ratio of graduations to total hirings reaches nearly 65 per cent, while contract cancellations in that interval have totalled

only 40, giving a ratio of graduates to total contracts signed of practically 90 per cent.

SELECTION

12. It might be well to pause here for a few moments to discuss the methods of selection which have brought about this improvement and, at the same time, have largely relieved the shop organization of the duty of culling out the undesirables. We do not employ any complicated interviewing system or any of the so-called aptitude tests or examinations. Of course, the interview is calculated to build up as well as is possible a correct first impression of applicant. His general appearance, manner, bearing and personality are given their proper consideration and much emphasis is placed upon consistency between his high school curriculum, if any, and the trade he is seeking. But what is more important than all of these, provided we think that an applicant is acceptable, he is first given a trial on what has been our proving grounds for years.

PRELIMINARY TRAINING

13. The Milwaukee Vocational School is equipped to give preliminary work in some 90 different occupations. If our applicant does not come to us already recommended by the Vocational School, we send him there for a period of weeks, during which time he is placed at work on actual operations of the trade he is seeking under the supervision of instructors trained in vocational guidance. If he survives their searching analysis of him, he is brought into the plant and the chances are that he will succeed.

14. We place almost implicit faith in the decisions of the Vocational School staff regarding these boys. However, when the boy is finally placed on the job, he still has the probationary period of his apprenticeship to serve and his contract is not signed until he has done that satisfactorily. With reference to the above figures of 40 and 65 per cent, much of this turnover has occurred among boys who proved out well as to mechanical ability but who dropped out for other reasons.

15. While this plan calls for some considerable advance planning and anticipation of needs, it has saved the shop supervisory personnel many unpleasant contacts with possible apprentice material, has served to keep faith with those whose patience with boys

may be a bit short and has put into practical use for the company that portion of our tax money which is used for schools.

16. Up to this point, generalities have been dealt with, and the figures quoted have covered the entire program with no attempt at segregation by departments. There are, however, some interesting things to be said with respect to the foundry and pattern shop apprenticeship. While apprentice graduates from all departments have forged ahead in their particular occupations, both with the Falk Corporation and elsewhere, the foundry end is of particular interest.

Foundry Graduates

17. Up to the present, there have been 62 apprentices graduated from the foundry. Of these, 35, or 56.5 per cent are now employed in the Falk shops, while 27, or 43.5 per cent are working elsewhere. Out of the 35 now employed by the company, the following have attained positions of responsibility:

One is a general foreman over about half of the shop, has about 200 men under his supervision, and is probably the logical contender for superintendency of the foundry.

Two are foremen of smaller departments, each with about 35 men directly under him.

Three others are being groomed for foremanship and are occasionally given charge of small crews.

One has been in charge of casting inspection for several years.

Another has complete supervision over sand conditioning and has conducted a number of investigations into sand mixes. A more recent apprentice graduate is his assistant.

One man is in charge of the annealing ovens.

Two are first helpers on the melting platform.

18. Of the remaining 23, eleven are molders on heavy work ranging from five tons upward, while the remainder are on lighter work and in the core rooms.

19. The above figure of 56.5 per cent has, of course, been somewhat influenced by the depression. Some apprentice graduates have been lost to the company through layoffs and will some day again be on the company payroll. Others have left during the worst of the depression to take work in other foundries, while 3 out of the entire 62 have left the metal trades entirely.

20. This is a record of which any employer of apprentices

may well be proud. The contribution to the business of the company is evident although difficult to measure in terms of dollars and cents. What is still more intangible, but none the less real, is the contribution made by the company to the trade in general through the apprentice graduates still employed by it and, more particularly through those who are working elsewhere.

POSITIONS HELD

21. Of the 27 Falk graduates who have gone elsewhere to work, nine have attained positions of responsibility with their employers.

Two are superintendents of fair-sized foundries, one of them specializing in alloy irons and the other in non-ferrous metals.

Five have attained foremanships in large and small plants.

One is a general foreman in a small shop.

One is employed by the State Board of Vocational Education as an itinerant instructor in foundry technology, instructing foundry apprentices in small communities where no regular vocational school exists.

PATTERN SHOP GRADUATES

22. In the pattern shop, 21 graduates have been produced during the past 15 years, nine of whom are working elsewhere and one of whom is apprentice instructor and sub-foreman in our shop. There is not the opportunity for advancement and promotion in this trade that exists in the foundry trade and, because of that fact, the figures with reference to the pattern shop may seem a bit pale in comparison with those for the foundry.

23. On the other hand, a good percentage of the company's pattern shop personnel is made up of the product of the company's training program, both prior to and since 1920. Many of these men have left in the interim and worked in other pattern shops and have come back to the company the more valuable for the experiences they gained. They are men who have grown up with the company's products, can appreciate the company's policies and traditions as to skill and craftsmanship and are, generally, more val-

uable as workmen than any ordinary group of patternmakers who could be hired readymade.

Advantages

24. It is, perhaps, unfortunate that the scope of this paper will not permit of more information which would be most interesting and relevant. The author hopes, however, that he has shown that the Falk Corporation has benefited from its active interest in apprenticeship. This is not because the company has been lucky nor because of any boom period. The results are there and any one with foresight and willingness to plan ahead for a few years can achieve them, and in doing so, will bring benefit not only to himself, but, what is more essential, to the trade in general and to industry as a whole.

(Discussion of this paper begins on Page 343)

Some Suggestions for Starting and Carrying on a Foundry Apprenticeship System

By J. E. Goss,* Providence, R. I.

Abstract

There is a decided dearth of skilled molders in the foundry industry and the author points out that if foundries even approach production capacities of predepression days, the shortage will be acute. The author points out in this paper that the only way to remedy the situation is by apprentice training. In this paper, he outlines some of the points to be taken into consideration in apprentice training such as methods of selection of apprentices, testing prospects, age limits, rates of pay, piece work, requirements of a program, necessity of centralized activities, trial apprenticeship periods, agreements, kind of instruction, related work, etc. He draws on the experience of his company which for many years has trained foundry apprentices and relates some of the methods used in its apprentice training program.

1. Suppose that dealers in foundry sand had gradually been going out of business during the past decade, and that the few who were left kept their stocks so low that the situation seriously affected our production. Let this supposition go on to the point where it was forseen that within the next few years there would be no more foundry sand available from dealers.

2. Of course, steps would immediately be taken to remedy the trouble. New mediums of supply would be established, not only with present needs in mind, but with assurances for the future.

3. The same action would be taken in the case of pig iron, facing compounds, or any other foundry commodity. Is it not amazing, therefore, that so few foundries are doing anything about the most important factor in their entire production system—skilled workers—when they are so well aware that the situation is even more serious than it would be if the sand dealers were unable to fill orders?

4. It passeth all understanding why foundrymen should buy

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Note: This paper was presented at a session on Apprentice Training at the 1935 Convention of A.F.A. in Toronto, Canada.

the latest equipment, test their raw materials, install up-to-date cost finding systems, spend money on research for new output, etc., yet do so little about the training of personnel—the thing so vital to all the rest. For too many years, foundrymen have been building superstructure on a crumbling foundation.

Apprenticeship Breeds Loyalty.

5. One of the best reasons for apprenticeship has never, so far as the author can recall, been brought out. It is that men taken in at an early age, given a good training, and thereafter kept employed so long as their work is satisfactory and there are orders for them to fill, are quite likely to be loyal to their employers. They are not nearly so liable to initiate, or even to follow, the radical ideas which are so rife among floating personnel.

6. In these days, when most anything may happen, it should be some consolation to a foundryman to know that the backbone, at least, of his organization is a part of his industrial family, able and likely to be reasonable, and with an understanding that the interests of employer and employee are one and the same.

7. So far as certain classes of people in foundries are concerned, foundrymen have no misgivings. Their plans could be made years ahead with confidence. Why not extend this scope to include men on the side floor, at the bench and at the machines? This is not idealistic. It has been, and will continue to be, a practical means whereby a vital part, if not all, of an organization can be trusted.

Shortage of Molders

8. The need for good molders is acute, even with tonnages far below normal. When the foundry industry approaches anywhere near capacity production, it will be faced with a very serious shortage of skilled men.

9. Investigation has shown that about 5 per cent of the skilled men a year normally are lost through death and other causes. This means that during the past five years, 25 per cent of the experienced molders have been lost. In addition to the expected 5 per cent annual loss, the industry is handicapped, at this time, by the loss of men who have, during the depression, gone to other kinds of work, such as operating gasoline stations, road-side stands, and small farms. No doubt many of these men will never return to foundry work because their new line of work assures them a

steadier income, although, perhaps in most cases, much less than they had been earning as molders. Other men, not able to secure employment in foundries where they formerly worked, have moved elsewhere, hoping that something might be found in a new locality. While this class does not represent a total loss to the industry as a whole, it has affected individual foundries to a considerable extent.

10. During the years that molders have been dying, moving away, getting into other lines of work, and becoming too aged for foundry work, very little training has been done. The problem seemed to be to keep the older and better men employed rather than to send them home and replace them with apprentices. Even prior to the depression, there was but comparatively little training being done. Foundrymen, generally, seemed to be in accord with apprenticeship ideas, yet they took no action, or insufficient action, about filling the depleting ranks of molders. Some gave as a reason that machines would do much of the work. This, at best, was simply an excuse. It is true that machines are doing more of the work than formerly, but also it is true that the foundry still needs men trained as all-around molders, and probably will do so for some generations to come.

11. How else can molders be obtained other than by training? It is readily admitted that stealing molders from one another is bad business. Even men not stolen, but coming from places far outside the towns in which foundries are located, are likely to be unstable. They may work for a few weeks or months to get a little money ahead, meanwhile working half heartedly and with the thought of getting back to their home towns and families as soon as any work near home presents itself.

START WITH GOOD MATERIAL

12. It is important in apprenticeship to start with good material. No doubt many plans have failed because they were thought by foremen and those higher in the organization, to be a means whereby relatives and friends could secure work. It is a splendid idea to have the apprenticeship organization so set up that it need not succumb to pressure in placing apprentices.

13. To get good material, the right sources of supply must be contacted. High schools, vocational training schools and CCC camps are three sources from which desirable applicants can be obtained, but these, and many other sources, must be contacted

before young men will come to the foundry from them to learn the molder's trade. No elaborate or expensive program is necessary to make opportunities in the foundry known to the right people. A little booklet, leaflet, or even a circular letter with the right circulation, will do much toward bringing applicants to foundries. Personal visits to schools, especially just prior to graduation, are often very effective, although not necessary to get results.

14. For the smaller foundry, able to absorb but a very few applicants, the housing problem for apprentices perhaps would not be a factor, inasmuch as a small number of very desirable young men might be secured from the immediate vicinity, and live at home. In the larger industries, however, apprentices are often hired from far away places, and if the job is done properly, a boy should not be sent far from a location miles away and simply turned loose to find a place in which to live. For many years, Brown & Sharpe Mfg. Company has maintained dormitories for its out of town apprentices. These have served not only to properly house the apprentices, but as a means of training in social aspects and of forming friendships which in later years prove very valuable both socially and in a business way.

Testing Prospects

15. There are various means of separating the chaff from the wheat among applicants. School records, and letters from school principals and teachers of vocational subjects are helpful. Mental ability tests and mechanical aptitude tests, requiring only a few minutes of the time of the person giving the test, can be made a distinct aid in determining the fitness and the probability of success of an applicant.

16. In foundry work, a physical examination is important. The applicant may appear robust and perfectly healthy, yet have a heart or other ailment which might develop into very serious trouble.

17. Selection of apprentices can be carried into the "red tape" category, but on the other hand there is very good reason for very careful selection. Most foundries take great pains in checking their raw materials which are going to be in use perhaps only a few days. Why should not even greater care be used in checking material which may be with us for many years?

18. Apprentices may be started in groups or individually. There is much to be said in favor of starting them individually in

that openings in the foundry are most likely to come not many at a time, but one at a time. Furthermore, when apprentices are started singly they can be shifted about from job to job to better advantage. When they finish their training period, it becomes necessary to find work for but one at a time, rather than for an entire group. It is the author's opinion that there is no advantage in starting apprentices in groups.

AGE LIMITS

19. Wages and age limits for apprentices always have brought about differences of opinion among foundry managements. The minimum age limit for foundry apprentices probably should not be less than seventeen years. Even so, there are comparatively few boys of that age who are developed well enough physically to begin foundry work. The maximum age may be twenty or perhaps a year or two more. If the maximum age is too high, there is danger that the apprentice may be lost during his course because he has come to the point where apprentice pay is not sufficient for needs of one of his age.

20. To illustrate this point: Some years ago, the author's company took an apprentice two years beyond our maximum age limit. This was done after the applicant had written us letters swearing on his honor that he would complete his apprenticeship time and begging us to waive all objections because of his being over the maximum age limit. For two years his apprenticeship went along very satisfactorily. Then he came to us and very decisively told us that he was going to leave us immediately because he felt that at his age he should take an opportunity which had been offered in another city. When he was shown the pleading letters which he had written two years before that time, he admitted that they meant everything when written but nothing whatever now. We have had no such experiences with apprentices taken within our regular age limits.

RATES OF PAY

21. In starting and carrying on a foundry apprenticeship system, it is well to give very careful consideration to rates of pay. Some years ago, there was a feeling among foundrymen that, to get apprentices, a rate of pay much higher than that for apprentices in other lines would have to be made to attract boys. While the wage rate probably should be somewhat higher than rates for ma-

chinists, draftsmen, or other apprentices in the metal trades, it should not be made so high that the prospective molder will look upon it as the main reason for his taking up the course. Perhaps a good way is to set a wage rate for the beginner which will enable a young man 19 or 20 years of age to pay his board, his room rent if he is living away from home, and to finance his incidentals and necessary clothing, and to increase this hourly rate by a few cents periodically during the apprenticeship.

Piece Work

22. There always will be a controversy as to whether apprentices should or should not be given piece work. Opinions are heard on every side that the purpose of apprenticeship is for the boy to learn a trade and that he cannot learn as well if he is charged with certain production requirements. This point can be clarified by asking the question as to whether or not quantity is a factor with quality in a modern production shop.

23. Suppose the apprentice is carried for a term of years, becoming at the end of that time a man who can turn out unusually fine castings. Suppose that this man is an absolute failure when it comes to producing those castings in anywhere near the time in which they must be produced if they are to be sold at market prices. Unless the boy is taught the time factor along with the quality factor, a desirable molder has not been produced. Of course, production requirements for apprentices should be reasonable. Whereas a journeyman molder rightly is required to produce his work within the alloted time, the fact must be taken into consideration, in the case of apprentices, that all the time spent upon a particular job is not in all cases spent upon the actual production of that job. Part of it may have been consumed by getting instructions, some more of it may be charged to asking questions of a foreman or nearby journeyman. While it is well to teach apprentices the value of production, it would be very bad practice to put this ahead of teaching the trade.

24. During the trial period, some attention must be given to the efficiency of the newcomer, but the foreman, and rate setters, and clerks, whose business it is to make black marks against poor time performance, should understand that the production expected of a journeyman molder cannot be expected of the new apprentice. Foremen who have had little or no experience with apprentices may not know what they should rightly expect of time so far as efficiency

in the early stages is concerned. While various means may be devised for taking care of this phase of the work, the author's company has found that it is reasonable to rate an apprentice not only during his trial period, but during his entire course, at about 75 percent of the efficiency of the experienced man. By writing off 25 percent of the apprentice's time, just comparisons can be made between apprentices and journeymen, and between apprentices themselves. The 25 percent can be charged to training. This time must be paid for anyway, and by using this method, or one similar to it, the time is accounted for, and intelligent ratings as the boy goes along through his course can be made.

PROGRAM

25. To carry on apprenticeship successfully, a program must be established before any business can be done. This is essential not only for plant purposes, but for the psychological effect which it has on the apprentices themselves. No worthwhile young man is going to stay in a plant as an apprentice if he sees that he is being treated in haphazard fashion. He will question whether, at the end of his apprenticeship time, he can rightly qualify as a "Journeyman Molder". Of course, if boys are hired indiscriminately, simply taking those who happen to drop in at the employment office when an opening is available in the foundry apprenticeship course, worry about a program in so far as they are concerned is unnecessary. Many of them will not be the discriminating kind, nor will they stay long enough to make any difference one way or the other. But the young man who can be built up to the place where he can be rated as an exceptional molder and eventually as a foreman, is going to demand a course of training about which he sees some order, system and forethought.

26. A program is a distinct help to the foundry itself. Years ago, apprenticeship was left largely to a department foreman. No doubt some very good mechanics were thus made, but the duties of a foreman today do not permit him to make a first class job of apprenticeship without help.

CENTRALIZE ACTIVITIES

27. Aprenticeship activities should be centralized, even though the foundry is a small one; that is, there should be some one person in the organization held responsible for training. He should see to it that the prearranged program is carried out with the aid and

cooperation of the foreman. No one foundry program will suit all, yet in making up a program the management should keep in mind the fact that the objective is to make a man who can rightly be called a journeyman.

Trial Period

28. Even though what seems to be very helpful tests are applied in the selection of apprentices, none probably will ever be found that are as good as an actual trial in the foundry. The test may be used to give some idea as to applicants whose probability of success in foundry work is very low, and these applicants can immediately be placed in the discard file so far as apprenticeship is concerned. However, it is not certain that all those who pass the various tests will actually do well as apprentices. It seems to be a good plan, therefore, not to make a contract with a boy before he starts work, but to first carry him along on a trial period. He should be paid the regular apprenticeship rates for this time, and the time should count as part of his apprenticeship hours. During this period, it is important that the beginner be checked very carefully so that, when the trial time is over, there will be no uncertainty about either contracting with him and his parents, or letting him go with the advice that he should seek something beside foundry work.

29. To check the opinions of those who have observed the trial apprentice and again to produce the proper psychological effect upon the beginner, it is well to have trial reports made at certain definite periods, and on certain definite forms. If the matter is left to a casual conversation between the foreman and the man responsible for training, the most desirable results will not be secured. No elaborate system is necessary, but just enough to have a record of what the various foremen think of those on trial in respect to such qualifications as workmanship, mechanical judgment, deportment and industry.

30. One side-light on the trial period is the loaning of tools to beginners. The plan in use in the author's plant is to have a certain number of sets of tools kept for this purpose, and loaned to the beginner during the trial. If he is signed as an apprentice at the end of this period, the loaned set is returned for use in another case and the apprentice is required to buy a set of tools.

31. The trial period is very important. Its duration may vary, but the author's experience has been that 3 months allows sufficient time for the foundry and the boy to decide definitely

whether or not they want each other. Occasionally, there may be some good reason for extending a trial for a short time, but this has been found not be the best practice. If the beginner does his best during the regular period, and it may be rightly supposed that he does, and if he is handled properly during this time, there should, ordinarily, be no indecision at the end of 3 months as to whether the boy should be accepted or rejected.

32. There are various opinions as to what is best to do with the apprentice while on trial. In some cases, management thinks it well to have the young man run errands or sweep the floor and do odd jobs, hoping in this way to familiarize the boy with the layout of the plant and also to get an idea as to his alertness and ability to carry out orders. The author does not approve of this method of treatment, inasmuch as a boy may be found to be alert and able to carry out orders such as would be given an errand boy, yet fail utterly in foundry work. It appears much better to give the beginner actual production work during his trial period, thereby making it possible to judge his fitness for the trade as well as his ability to carry out orders.

33. Since the beginner is not able to try out on floor molding jobs, the plan used in the plant with which the author is associated, is to start the boy in the light core department, where his hand dexterity can be determined, a factor which is important in the molders trade. If, during the 3 months' trial, a boy is found to be steady in his attendance, alert in his motions, able to carry out simple orders, and learns to make small cores well and within as reasonable a time as can be expected, the author's company feels that it is justified in signing the boy as a molder's apprentice, provided he himself wishes to go on with the trade.

AGREEMENT

34. In line with a definite job program and systematic means for checking the apprentice during his trial period, it is very essential that an apprenticeship agreement be made between the company, the apprentice, and the parent or guardian at the end of a successful trial period. In fact the term "Apprenticeship" should not be used unless a regular agreement is made. Some States have apprenticeship laws according to which such agreements must be drawn.

35. It is well to have apprenticeship agreements made in

appropriate form, and not simply in long hand on a letterhead. A foundry employing but very few apprentices need not go to the expense of printing apprenticeship contracts on expensive legal paper, but it can at least have the terms neatly typewritten, and the whole agreement made up in such a way that the boy and his parents will think of it as something worthy of their most careful consideration.

Fee

36. The practice in the Brown & Sharpe Mfg. Company is to require that the parent or guardian make a cash deposit at the time the agreement is signed, as further evidence of good faith. In the case of molders apprentices, the deposit is $25.00. Although the apprenticeship contract reads that this is paid "as compensation for receiving the apprentice," the company always has considered it simply as a deposit to be set aside to the boy's account. At the end of a successful apprenticeship, the company pays the graduate a bonus which, in the case of molder's apprentices, amounts to $100.00.

37. The matter of requiring apprentices to pay a fee sometimes is questioned. It might not seem necessary to go further than to have the boy and his parent or guardian sign the agreement, but the author's company has found that this practice obviates the signing of an apprentice who may simply want to work as an apprentice only until such time as he can secure another job. It is safe to suppose that a young man signing a legal form of agreement, together with his parent or guardian, and whose parent or guardian has made a cash deposit when such agreement was signed, will think very carefully before jumping from his contract within a short time, at least, after it has been made.

38. When the agreement is signed, it is time for the apprentice to have his own tools, although he may not be in the position financially to purchase them for cash. The practice used by Brown & Sharpe Mfg. Co. is to return the loaned set which the apprentice has used during the trial period to the stock room and to have the newly signed boy furnished with a set of tools which he can pay for on the installment plan out of his wages, if he so wishes. This so-called "regular apprentice set" is kept down to a minimum of tools, and the apprentice

is advised, from time to time, to add to the set such tools as will eventually make it complete.

KIND OF INSTRUCTION

39. One of the most important factors in foundry apprenticeship is the kind of instruction which the boy gets. If it is poor or insufficient and he has to shift for himself, it still is important because he probably will leave because of the inattention. If he can see that he really is learning how to become a molder, and that he probably is learning the most up-to-date methods, he most likely will stay. After all, boys are brought into foundries with the idea of producing good molders for future use, and if they are not given the necessary instruction, foundries are failing to serve their own purpose. It is well, if there are enough apprentices to warrant it, to assign a competent man as an instructor, but if this is not done, sub-foremen or gang leaders can be charged with the instruction of apprentices while working in their departments. To neglect in any way the instruction of foundry apprentices in the art of molding, after having gone to the trouble and expense of placing the right boy in the foundry, is like failure to deliver satisfactory goods after time and money has been spent on advertising and sales.

REPORTS

40. For the good of both the foundry and the apprentice, it is well to have some system whereby reports can be made and recorded. No top-heavy set-up is necessary for this. It is simply a duty of the man assigned to supervise the work of the apprentices. All that is required is a small printed or mimeographed form, a little time and conscientious thought on the part of the foreman or gang leader, and whatever few moments are necessary to record these reports in a central office. It would be poor business to carry an apprentice through 2 or 3 years of his time and then find that both his time and the company's had been wasted by not letting him go earlier in the course. Reports made periodically and conscientiously will prevent such a situation. They will also help the supervisors to correct faults which may appear from time to time in these young men.

41. In addition to the report covering grade of workmanship, industry, etc., the author's company has found that an "interview

system'' is very helpful. Unfortunately, many organizations are too large for daily contact between apprentices and officials or higher executives. The interview system does not serve as a first class substitute for the old, frequent, personal contact between manager and apprentice boy, but it is much better than no contact at all.

42. At certain times during the course, the apprentice is called to the office of an executive for an exchange of ideas. Each of these executives makes a typewritten report of his impressions. These are valuable in several ways, but especially in placement at the end of the course. To the boy, they are of incalculable value. Some man, whom he perhaps has held in awe, he comes to think of as his friend, interested in his progress and hopeful of his some day attaining a worthwhile position in the organization. Incidentally, this system serves as a check on the functioning of the apprentice department. By questioning the boys, the executives can learn much that they should find of value. The author's company has found that this system, intended for the apprentice to learn something through contact with the older man, has developed into a two-way informational process—the executive learning, in many instances, as much as the boy.

Related Work

43. In the twelfth century, the guilds in England recognized the fact that apprentices should learn something besides the manual work in the shop. In those days, the apprentice became a part of his master's household, where he was required to learn the catechism.

44. The question as to what properly should be included in related subjects for a foundry apprentice is often a debatable one. A foundry apprentice can be given for his class work only whatever simple mathematics and drawing would be required to make him a proficient molder, but a somewhat different class program should be made available to him if the company is looking ahead to the time when it may need him for work in its foundry requiring not only a knowledge of molding but the ability to do things which can be done only by a mind developed through a broader training.

45. The danger in making up a school program lies in the tendency to include various subjects which may have certain value, yet which are of little practical use even in the higher class of

foundry work. Physics and chemistry, for example, are subjects which no doubt have certain value to a foundry apprentice, yet it is a question whether even these subjects might be discarded for others which probably would do the apprentice more good in the end. Mechanical drawing is a subject which frequently seems to have too strong a position in a foundry apprenticeship school program. While the value of mechanical drawing is recognized, there seems to be no good reason for having a young man spend many hours of his valuable apprenticeship time drawing and inking machine parts. No doubt it is well for a foundry apprentice to know how to make a simple working drawing and to have enough drawing so that he will be able to read such blue prints as would come before foundrymen, but to make a major subject of drawing for the foundry apprentice does not seem wise.

46. If the modern theory of education, that school work is planned primarily to develop our thinking and reasoning powers, is accepted, then it might be said that physics, chemistry, mechanical drawing or most anything else would do as well as any other set of subjects. Yet it is possible, in making up a school course, to develop thinking and reasoning powers and at the same time give the boy something which he can directly apply to his work either as a journeyman molder, or later as a foundry foreman.

47. There are various ways of carrying out a school program. If the foundry is not large enough to warrant school facilities of its own, correspondence courses are sometimes used. At least one of these provides for supervised instruction, an essential factor in this kind of school work.

48. In the cities or towns where trade schools or technical high schools are not too far away from the foundry, arrangements usually can be made for apprentices to attend special classes at the schools, taught by the regular school instructors. In all the cases with which the author has been connected, the school authorities have been very glad to cooperate, but they usually are at somewhat of a loss to know just what the foundry wishes them to teach the boys. If foundry management and the school authorities would get together and spend time enough to work out a course, there would be no question but that this arrangement of having the foundry apprentices get their school work in a public school would work out very satisfactorily.

49. There is one point about this, however, which may be in

doubt, and that is the fitness of the school people to give the apprentices the practical talks about foundry work which may be made so helpful a part of the school work. This had better be done in most cases by a practical foundryman who is daily in foundry work and up-to-date in foundry practice. Although public departments of education are requiring more and more that instructors in trade schools be men with a background of practical experience, these men cannot be expected to treat the problems in any particular foundry as well as could a man who is daily doing a part of the work in that foundry.

50. Probably the most satisfactory means of giving foundry apprentices the related subjects is in foundry schools, but, if this is done, it is extremely important that the right men be employed to get the course together, to keep it up-to-date, and to give the boy the proper instruction in it.

51. The school plan at the Brown & Sharpe Mfg. Company has not included some of the subjects, aside from trade mathematics, which so often are found in an apprentice school. Instead, the company has thought it better to make-up its own course in such a way that it will promote, and check up, the study of foundry books and trade papers. This is done by questions on foundry work which cannot be answered except by the young man who has read extensively and asked questions of the foremen and others about him.

Foremanship Course

52. In addition to the regular school course for foundry apprentices, the author's company has a course in foremanship, by means of which our apprentices are given an insight into the functioning of various departments throughout the organization and an opportunity to study and to discuss problems which daily come before the supervisory force. It is made clear at the outset of this foremanship course that an apprentice should not assume that, because he takes the course, he will automatically become eligible for a foreman's job.

53. Underlying all successful apprenticeship activities must be the keen and vital interest of management. Apprenticeship will not be successful if management simply tells the foundry superintendent that it might be a good thing to have a few apprentices and to get some boys started. If business is done in this way the boys will get started, but they certainly will fail to stay. Nothing else

in the foundry is done like that, so why expect that apprenticeship should work that way. Management can no longer offer the excuse that young men nowadays will not go into foundry work, because it has been proved that applications will far exceed openings, provided a real opportunity to learn the molders trade is offered. Even during the 7 or 8 good business years prior to the depression, there still could be found plenty of good prospects to learn the molders trade. Of course, even the best apprenticeship system cannot help but occasionally lose a young man who for some reason decides not to go through with his agreement, but this is a rare occurrence in foundries where there is some semblance of system and order and where management is interested. There is no reason whatever why foundrymen should not try to sell the molder's trade to the youth and their parents any less than they try to sell new output ideas to the buying public. Selling apprentices does not take nearly as much money, but the returns can be made invaluable.

(*Discussion of this paper begins on Page 343*)

FOUNDRY APPRENTICESHIP

DISCUSSION

CHAIRMAN J. H. PLOEHN[1]: The most important thing that we are facing today is the training of apprentices to take the place of those workers who have fallen by the wayside in the past four or five years.

We must do something to keep our industry going and the more highly developed, the more mechanical, the stricter the specifications become, the more the gray iron foundry or the steel foundry becomes competitive with other fabrication methods, the more necessary it is going to be to have properly trained, skilled mechanics.

MEMBER: In connection with the vocational schools, what is the number of weeks that the applicant is kept in the school?

MR. HYDAR: The number varies. Usually we try to plan sufficiently ahead so that our applicants are at the school not less than about a month, and at times two and a half or three months.

MEMBER: Are all apprentices of high school grade?

MR. HYDAR: No, they are not. Our quotas, as I mentioned, are set up to provide three and four year programs. Generally, when a boy is a graduate of high school, particularly of a science course, or a technical high school, he is given a three year program.

We have set up a fairly definite ratio of three to four year apprenticeships, figuring generally that the boys in the three year apprenticeship will supply our supervisory candidates.

MEMBER: What kind of technical training is given the apprentices?

MR. HYDAR: The shop program is laid out in a definite schedule which is incorporated in the contract. It provides for work in green sand, dry sand, bench and machine molding. It provides for some core making, both on large and small cores, and a short period in the cleaning room in which we hope the apprentice will gain some knowledge of the results of his mistakes or his carelessness on the molding floor and on the bench. We make optional, also, some training in the melting department and in the annealing of castings.

As for the school training, the Vocational School has an apprentice department set up for just that sort of work alone. They have very definite programs of related training. The program is flexible enough, however, to go back and cover the more elementary things for those who need them and to take up the more advanced subjects for those who have already qualified in other things.

The related training includes shop mathematics, a little industrial chemistry, physics, safety, personal hygiene, heat treating, strength of materials, practical mechanics and similar subjects.

CHAIRMAN PLOEHN: I might say that you can get a course through some of the correspondence schools that is both practical and elementary. These courses were written, as I understand it, through the experience of Milwaukee and other centers, and include the practical technical knowl-

[1] French & Hecht, Inc., Davenport, Ia.

edge that is needed in a foundry or pattern shop, such subjects as shop mathematics, strength of materials, chemistry and physics.

The Milwaukee people have their vocational school with a fine personnel of instructors who are practical men. There are very few cities though, that have these facilities. I think Cincinnati and Pittsburgh have good schools. Some larger companies have their own instructors, technical graduates that can handle the various related subjects.

In our particular locality, our companies pay half of a correspondence and the boy pays the other half. He has to pay something or it is not worth while. If he graduates, we usually remit to him the money he has paid for his half of the course as a prize. During the time he is taking the course, we deduct from his wages so much a week or month to pay for his share.

MEMBER: Do the pattern apprentices have any molding experience during their training and do the molder apprentices have any pattern work?

MR. HYDAR: Our pattern shop contracts provide for about four months on molding and about a month in the core room. We have not included pattern work as a definite part of the molding program, although it is included in the optional part of the contract which I mentioned. Part of that could include pattern making. We take our molder apprentices to the pattern shop occasionally and show them the work.

CHAIRMAN PLOEHN: In our case, the boy, in the first few months of his probational period, is used as an errand boy, to take patterns to the pattern shop and to the core room and in that way he learns quite a little bit about pattern and core work.

Our molding apprentices in the last year are given a lecture by the pattern shop foreman about once a week, on their own time. He explains the various kinds of patterns, such as three-part and two-part and so on, and also the core boxes, the kinds of core boxes—plaster, wood and metal, and how they should be handled and why.

B. G. PARKER[2]: Have you a definite schedule of compensation for your apprentices?

MR. HYDAR: Yes, we have. The contract, now that the 40-hour week has become the regular thing, is divided into periods of 1040 hours each. 1040 hours is just a trifle over six months of steady employment and each period of 1040 hours is specifically assigned a certain pay rate. The lowest starting rate is 28 cents an hour and the finishing rate for all contracts, regardless of whether a three or four year program, is 55 cents.

MR. PARKER: We had a great deal of difficulty with the compensation features of apprentices starting with a low rate. We did not have any success until we started a boy with the common labor rate of 40 cents an hour. In our district, we now put the boy on a probation period. If at the end of that time the supervisor thinks he is going to make a mechanic, he automatically gets an increase of two cents an hour. Every two months, he gets an increase.

Starting a boy at a low rate, it took two years for him to get up to

[2] Youngstown Foundry & Machine Co., Youngstown, Ohio.

the ordinary labor rate and we lost him. He knew that in other shops they paid a boy sixty cents an hour and he could not withstand the temptation to leave. We have eliminated that unfortunate feature and we think it pays.

MR. HYDAR: Were the boys with whom you had that difficulty under contract, signed, sealed and delivered?

MR. PARKER: Yes.

MR. HYDAR: We have found the signing of a contract helps to steady the boys materially. Once the contract is signed and in force, they do not seem quite as susceptible to the greener pastures.

One foundry in the Milwaukee district has always contended that it had difficulty in keeping its apprentices on the lower schedule of pay and it started the boys on 38 cents an hour. They claim that since they are out on the edge of the community, their boys have to come a long distance and this seems to be discouraging to them. However, other foundries not very far removed from them have paid the schedule generally prevalent in Milwaukee and have had little difficulty with that sort of thing.

MR. PARKER: The trouble we had was that when the boy served two years, he was getting 35 or 40 cents an hour and was working alongside a man making 60 cents an hour and he was doing just as much work. It did not keep the boy satisfied. He became a sort of bolshevist and it was not fair. I still think it is not fair because after a boy serves two years of his time he comes through with his day's work just like the skilled mechanic who is getting 80 or 90 cents an hour.

MR. HYDAR: Of course. Our answer to that view has always been that the boys are getting the advantage of the school time for which they are paid and of the lectures which are given them once a week in the plant, usually for a matter of a half hour to 40 minutes; and of course of the supervision and the transferring back and forth from one thing to the other.

CHAIRMAN PLOEHN: I might make a little suggestion which we found from experience to be very valuable. That is that apprentice means a boy and we have found it wise not to hire them much over 18 years old.

First of all, when he is a little younger he lends himself to school work more easily than after he gets older. Then he is satisfied to work at an apprentice rate, and by the time he gets to be 20, 21 or 22 years old, he is making more than a common laborer and he has learned his trade.

The experience we have had, when boys start who are about 19 or 20, is that they may want to get married or run around with older boys who make more money. They have learned enough to be specialty men and they leave you, which has a bad effect on the rest of the apprentices. You have put in a year or two of time on them and when they quit they have broken the chain of your apprenticeship system. So we have rather set the rule not to hire them past 18 years of age.

Our rates are similar to Mr. Hydar's, in Milwaukee. They are practically the same as the Federal Apprenticeship Wage Plan, being an

average of fifty per cent, over the period of the apprenticeship training, of a journeyman's rate.

MEMBER: Does Mr. Hydar's firm pay the apprentice when he is going to the vocational school in this preliminary test?

MR. HYDAR: There was a time when we did pay our boys for the preliminary time they put in at the vocational school, prior to the time they were brought into the plant, but we do not find it necessary to do that any more.

MEMBER: What rate does the apprentice draw at the end of four years?

MR. HYDAR: The final period, as I said, is at the rate of 55 cents per hour. On an average our apprentices are paid 64 cents per hour on completing their apprenticeship.

MEMBER: Does he have to make up time lost during the apprenticeship before the contract is up?

MR. HYDAR: Yes, the contract is written in hours. The statement in the contract with reference to the term of training is worded in about this manner:

> "The term of apprenticeship shall consist of eight periods of 1040 hours each or a total of 8320 hours or approximately four years."

so that the contract is really based on service hours rather than on months or weeks.

G. W. CANNON[3]: Who signs the contract besides the boy? Have you anything in a sales way that points out the benefit of apprenticeship in the foundry business that you could present to the boy to take home to his parents?

We have found that we have to sell the parents of the boys, so that they will back the boy while he is going through the apprenticeship period. Unless the parents know the advantages, we have found it quite hard to keep the boy on the job. The parents are the hardest ones in a good many cases to whom we have to sell the advantages.

MR. HYDAR: The contract is signed by the boy, his parent, or guardian and the employer and is subject to the approval of the Industrial Commission of Wisconsin. In the event that a boy does not have a guardian or a parent, which happens occasionally, then a member or a deputy of the Industrial Commission can sign the form and becomes automatically his guardian during the apprenticeship.

We have a mimeographed prospectus about all of our apprenticeship training programs. It is made up in sections. The sections are all separate so they can be bound in a soft cover, either altogether or in whatever combination we choose. The first section is entirely on general considerations regarding any sort of apprenticeship and other sections deal with the specific trades, the foundry, machine shop, pattern shop, drafting, and all the other apprenticeships we have had.

They set forth both the desirable and the undesirable features of the plan so the boy can go into the matter with his eyes wide open.

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[3] Campbell, Wyant & Cannon Foundry Co., Muskegon, Mich.

MR. CANNON: Do you pay a premium to the boy who finishes his apprenticeship?

MR. HYDAR: We have a bonus of $75 for the three year boy and $100 for the four year boy, payable on completion of the contract. If the apprenticeship is terminated through no fault of the boy, that is, if the company has to transfer him to another shop (which we have not had to do but which has been necessary in some cases in our district), the company will pay that portion of the bonus proportional with the amount of time he has served and the new company that takes him on pays the balance.

CHAIRMAN PLOEHN: I might add there is a little booklet printed by the National Founders Association, called "The Foundry and the Boy." You can get it from their office, 29 So. La Salle St., Chicago. It goes into the desirability of a boy learning the foundry trade.

The National Founders Association and the A.F.A. last year jointly published a recommended four year course on foundry apprenticeship on which their committees had been working on for a number of years and which goes into detail as to the courses in a foundry. It explains how to set up a course and what to do, of what the course should consist and in general has quite a lot of information for the average foundryman who has not had any experience in apprenticeship work.

MEMBER: Do you group your apprentices or do you scatter them throughout the plant?

MR. HYDAR: In the small end of the foundry where our lighter jobs are made, most of the floor work is done by apprentices and of course they work rather in a group. When they are transferred from that department to the heavier work they are scattered.

MEMBER: Are boys who have been working around the foundry and later decide to learn a trade allowed any credit for the time they have been around the factory, if they take up a contract for apprenticeship?

MR. HYDAR: We make allowance on the contract for previous experience, depending on the quality of the experience. If they have served as helpers only and have not been in contact with a large variety of work they will not get as much credit, perhaps, as those who have been helpers and have shown some tendency to get ahead on their own and maybe have been given responsibility.

CHAIRMAN PLOEHN: In connection with related school work, if you have a high school, your school board can get aid from the Federal and State Vocational Department under the Smith-Hughes law, which will pay half of the instructor's time while he is doing this work. It might be well to keep this in mind also on courses for foremen training. There is no red tape or much trouble, except for the school board, to make application and see that the work is properly done.

CHAIRMAN PLOEHN: Mr. Goss, how many years have Brown & Sharpe had apprenticeship training?

MR. GOSS: The company started business 102 years ago and I am

quite sure apprentices were taken from the outset. We have records of boys having been graduated 78 years ago.

CHAIRMAN PLOEHN: To revive our training program, we had a little meeting last November in our district in which we called together one or two of the representatives of various companies in our association, the Tri-City Manufacturers' Association, and we put before them this question: What are you going to do for men this winter and spring?

These men were all executives so we said to them, "You are going to make certain products. You are going to get an order for them. You then issue orders to make certain products and they have to be up to certain specifications."

"Now, to get you apprentices the only thing to do is to put the order out to make mechanics and see that they are made along certain lines and certain specifications." These specifications, as Mr. Goss has said, do not need to be very elaborate or involve very much red tape, but you have to take the time and trouble to teach these men the trade. It is the same as your manufactured product—you have to take the time and trouble to have certain specifications and see that they are followed to make a good product.

One of the most important things that the foundry has to solve within the next few years is the question of skilled personnel.

MEMBER: Has the speaker found that the apprentices that came from the homes of molders or foundrymen made better apprentices than those who came from the outside?

MR. GOSS: We have not found any difference between the boys whose fathers were molders and who were acquainted with the foundry in that second hand way, so to speak, and boys who had no such connection. One of the last apprentices we took was a son of one of our very good molders. There seemed no difference between him and a boy we had taken just before he came to us, who had no connection at all. I think you should get the right boy, mentally and physically, regardless of whether or not he knows anything about a foundry.

There is just one thing I would like to add. Sometimes Brown & Sharpe are thought of as carrying on apprentice training as a matter of tradition. That is not the case at all. We do it as a matter of good business. It is a very vital part of our business; something we do not know how we would get along without. It is a necessary function.

MEMBER: Mr. Goss referred to piece work and stressed that the time element had to be followed as well as quality. Does his company follow the practice of putting the apprentice on piece work and allowing him to earn the same as the journeyman?

MR. GOSS: We give the boys piece work because quantity is a very important factor along with quality. Undoubtedly it does offer the boy some incentive to make more than his regular rate.

We have what we call a wage incentive plan. Most people call it a piece work system. The boys thereby sometimes do make more than their regular apprentice rate. We have had that system in the machine shop for quite some time now, but it is in the process of being worked out in the foundry. We do not know exactly how it is going to work

so far as the apprentices are concerned. We do know that prior to the wage incentive system we had the straight piece work system and that the molder apprentices did make, in many instances, more than their day's pay.

MEMBER: Do you find any difficulty in transferring them to the next operation?

MR. GOSS: Not at all. We have many assignments throughout the foundry and machine shop. A boy may make eight or ten cents an hour bonus on one and nothing whatever on the next. He knows very well that on certain kinds of work he will not make a bonus because of the nature of the operation.

CHAIRMAN PLOEHN: We have had the same experience. We have had no trouble with our apprentices in putting them on piece work to let them make a little extra money and then when the rush is over, whether it is a matter of weeks or months, transfer them to other work on their regular day rates.

As Mr. Goss has stated, it has given them a picture of production of quantity as well as quality and also the incentive to earn a little more.

MEMBER: For the piece work of an apprentice do you pay the same piece work rate as for the journeyman on the same job?

MR. GOSS: No, we write off 25 per cent of the boy's time. For example, if a boy spends 10 hours on a 7½ hour job, we say he did it in 7½ hours. We simply forget one-quarter of the time he spends on that job.

MEMBER: Does the speaker think the ability to read a drawing is of more importance than many other things in a foundry?

MR. GOSS: We give the boys enough mechanical drawing so that they will be able to read drawings. We think it quite important. We go even further than giving them ordinary mechanical drawing. It is sometimes necessary for a foundry foreman to get ideas over to a man who does not understand working drawings, so we teach the boys isometric drawing, with a pencil and straight-edge. We have found this very helpful in many instances.

CHAIRMAN PLOEHN: As stated here today, the large organized plants that are having regular apprenticeship programs can only make about 20 per cent of the mechanics necessary. The other 80 per cent have to be made in the smaller shops employing from six to 20 or 30 men. Usually the smaller shops make better men because they are jobbing shops that have more problems sometimes in their work than the larger shops.

You must get those men started, get some one interested in those foundries to see that they put the necessary force behind their organization to train as many boys as they can take care of. A good boy in a foundry is worth all that he gets; he is valuable and can be used to good advantage. He may be a slight cost to the company the first year or two but he will make up for that in his other two years, so it should

not cost the average foundryman a cent at the end of four years, so far as the results of the boy's work are concerned.

If each small foundry will take one or two, or in the proportion of one to five in a small shop and one to ten in a large one, we are going to have mechanics.

With the highly organized mechanical foundries, the better quality of castings necessary, and the alloys that are being used, it is going to be more necessary to have skilled mechanics in the future than it has been in the past. If each one of you will go out in your own locality and see that the foundries do their share, I think we will have done our part to keep our industry up near the top where it should be.

A final thought I wish to leave is this: We have had no trouble in our locality in securing a waiting list of boys to work in a foundry. In fact, right now we have a waiting list of over 200 boys. I am not saying that they are all good or that they will all be accepted but if business keeps on at the present rate I think a large number will be taken in. You can get boys to work in a foundry. To use the old saying, "Well, you can't, but you can."

I think the foundry is a better place than the machine shop. I think it takes a better man to be a molder than a machinist. I am not saying a tool maker. The average molder has to have a little more skill and a little better knowledge of basic engineering than the machinist. So we use our best material in the foundry and we can convince these boys that that is their best opportunity.

Fabrication of Cast and Rolled Steel

By J. M. Sampson,* Schenectady, N. Y.

Engineers have questioned the practicability of welding cast steel to other types of steel. This attitude was due to the lack of information on the subject. To supply this needed data, the company with which the author is associated, undertook an investigation to determine data that would be of use to its engineers in solving the problem and would determine the satisfactoriness of various procedures. This paper outlines the results obtained.

1. The fabrication of frames of machinery and apparatus, in which cast and rolled steel are combined by arc welding, has been, to a slight extent, an accomplished fact for some time. Development of the process was retarded by the absence of basic data essential to engineering design. While it was believed that welds could be made which would develop the full strength of the members involved, still doubt existed and, therefore, it became necessary to determine the properties of welded joints of cast to cast and cast to rolled steel. An example of this type construction is shown in Fig. 1.

2. Engineers and foundrymen have considered the advisa-

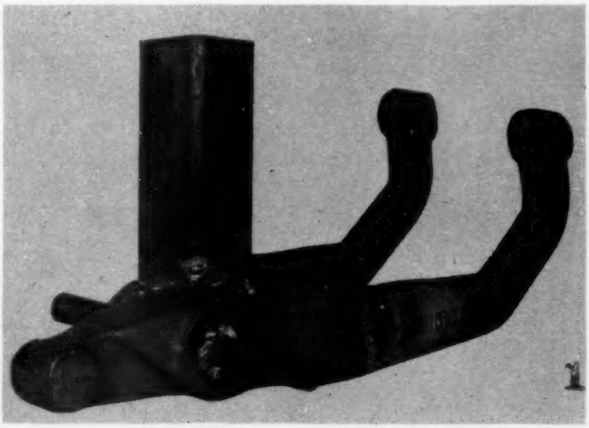

Fig. 1—An Example of Welded Construction Involving the Welding of Cast Steel to Cast Steel, Cast Steel to Structural Steel and Cast Steel to Cold-Rolled Steel. Cast Steel Was Welded to Cast Steel as Noted in the Lower Member.

* Foundry Engineer, General Electric Co.

Note: This paper was presented at a session on Steel Founding at the 1935 Convention of A.F.A. in Toronto, Canada.

bility of the use of combinations of cast and rolled steel and have believed that better and cheaper frames could be fabricated by using such combinations. Costs can be estimated after designs are prepared but designs are dependent upon adequate test data.

DESCRIPTION OF TESTS.

3. Tests were made to obtain physical data for welded joints of cast steel to cast steel, cast steel to hot rolled steel, either as bar or plate stock, and cast steel to cold rolled steel. The cast steel used in these tests varied in carbon content from 0.31 to 0.39 per cent and the rolled steel was the usual material available in the factory. Most of the joints were arc welded by use of bare electrode, type L, and fluxed electrodes, types W-20 and W-21. Some joints were flash welded.

Materials and Preparation

4. The steel surfaces to be welded were grit blasted, gas cut, machined or sawed, to determine the effect of surface treatment. Materials were, at times, annealed before welding and some specimens were annealed after welding to determine the effect of annealing upon physical strength. The materials used were the ordinary run of materials readily available, and most of the welds were left rough or in the condition they would be left in a manufactured product. Some of the specimens were machined for comparative purposes, but actual working conditions were always given preference in preparing test conditions.

Tests

5. Four general types of tests were used: Tension, shear, bending, and fatigue.

6. Tension tests were made on specimens as welded and also on specimens machined to meet A.S.M.E. Boiler Code requirements. Shear tests were made of fillet welds to meet American Welding Society Structural Code requirements. Bending tests were made to determine characteristics of joints when subject to severe distortion and some specimens were machined to meet A.S M.E. Boiler Code free bend test requirements. Fatigue tests were made to study the behavior of welds in combinations of cast and rolled steel for parts subject to reversal or variation in stress.

Tension Tests

7. Tension tests consisted of:

1. Seven series of nine specimens each with the specimens left as arc welded.

2. Three series of nine specimens each with joint ground flush after flash welding.

3. Three series of nine specimens each machined to accurate test specimen sizes for A.S.M.E. Boiler Code tension tests.

Shear Tests

8. Shear tests consisted of eight series of three specimens each with the specimens left as arc welded. Those test specimens were made in accordance with Fig. 54, page 109, of the Report of the Structural Steel Welding Committee of the American Bureau of Welding, September, 1931.

Bending Tests

9. Bending tests consisted of:

1. Three series of nine specimens each, with the specimens left as arc welded.

2. Three series of nine specimens each, with the joint ground flush after flash welding.

3. Three series of nine specimens each machined to accurate test specimen size for the A.S.M.E. Boiler Code free bend tests.

Fatigue Tests

10. Fatigue tests consisted of three series of four specimens each, machined in accordance with standard fatigue test specimens used in the General Electric Company research laboratory.

11. Tests have been grouped in this report to suit the needs of the engineer in seeking information as to processes available and combinations possible when involving welds subjected to tension, shear, bending, or fatigue.

Results

12. Tension tests indicated the necessity of using a fluxed electrode such as W-20 or W-21. Specimens welded with fluxed electrodes not only show superior results over bare-wire electrodes with respect to tension, but very much better results with respect to ductility. (See Fig. 2.)

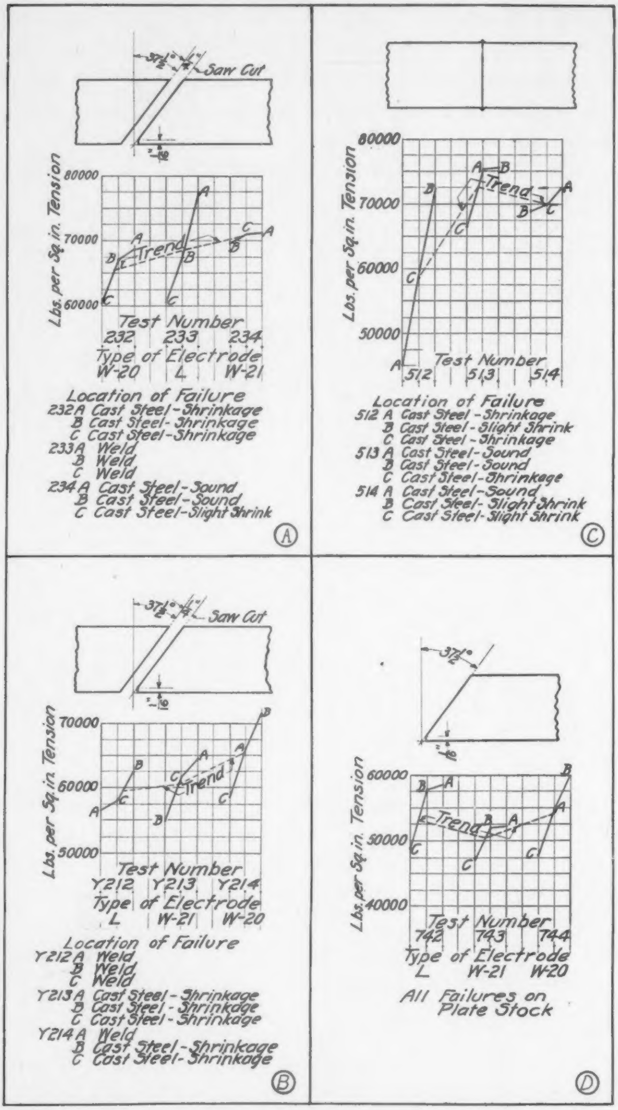

FIG. 2—RESULTS OBTAINED ON UNMACHINED TENSION TESTS OF WELDED SPECIMENS, (a) CAST STEEL TO CAST STEEL, ARC-WELDED BUTT WELDS, SERIES 23, (b) SAME AS (a), SERIES Y21, (c) CAST STEEL TO CAST STEEL, FLASH WELDED, SERIES 51 (SEE FIG. 7), (d) CAST STEEL TO PLATE STOCK, ARC-WELDED BUTT WELDS, SERIES 74 (SEE FIG. 7). FOR DATA, SEE TABLE 5.

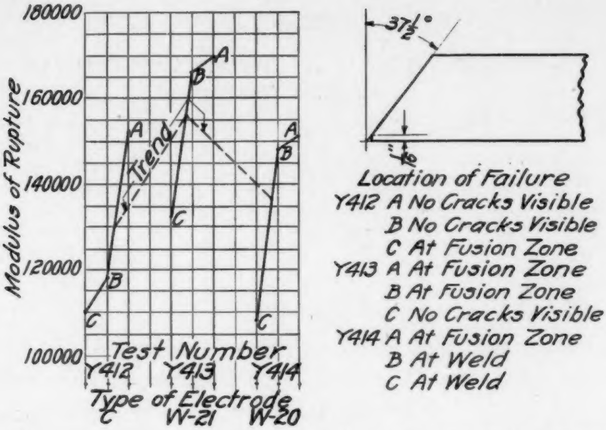

FIG. 3—RESULTS OBTAINED ON UNMACHINED BEND TESTS OF WELDED SPECIMENS, CAST STEEL TO CAST STEEL, ARC-WELDED BUTT WELDS, SERIES Y41 (SEE FIG. 8). FOR DATA, SEE TABLE 6.

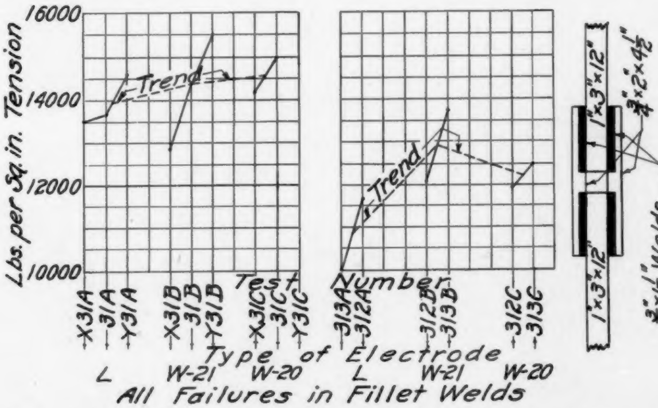

FIG. 4—RESULTS OBTAINED ON SHEAR TESTS OF WELDED SPECIMENS, (LEFT) CAST STEEL TO CAST STEEL, ARC-WELDED FILLET WELDS, SERIES 31, X31 (SEE FIG. 9) AND Y31, (RIGHT) CAST STEEL TO PLATE STOCK, ARC-WELDED FILLET WELDS, SERIES 312 AND 313 (SEE FIG. 10). FOR DATA, SEE TABLE 7.

13. Shear tests showed that fillet welds have about the same strength on cast steel as they do on rolled steel, also that annealing does not appreciably affect the results. Inaccurate fitting of surfaces has a noticeable effect on the lowering of test results.

Table 1

STRENGTH VALUES OF ARC-WELDED CAST STEEL TO PLATE STOCK SPECIMENS

Cast Steel Bars, Tensile Strength, lb. per sq. in.		Plate Stock Bars, Tensile Strength, lb. per sq. in.
76,600	Maximum	59,800
52,100	Minimum	46,300
64,300	Average	53,300

Table 2

FAILURES IN ARC-WELDED CAST STEEL TO CAST STEEL SPECIMENS—IN AS-WELDED CONDITION WITH REINFORCING LEFT ON

	Failure in Weld With Type L Electrode at	Failure in Weld With Type W-20 Electrode at	Failure in Weld With Type W-21 Electrode at
Maximum, lb. per sq. in...	77,600	68,900	No Failures
Minimum, lb. per sq. in...	48,800	65,700	In Weld
Average, lb. per sq. in....	61,100	66,900	....
Per cent Failures in Weld to Total Welded........	80	20	0

Table 3

FAILURES IN ARC-WELDED CAST STEEL TO CAST STEEL SPECIMENS WELDED WITH TYPE W-21 ELECTRODE

	Failure in Weld at	Failure in Cast Steel at
Maximum, lb. per sq. in......................	83,700	75,200
Minimum, lb. per sq. in.....................	71,500	65,900
Average, lb. per sq. in......................	77,030	69,770
Per cent Failures to Total Welded..........	83.3	16.7

Table 4

FAILURES IN ARC-WELDED CAST STEEL TO PLATE STOCK SPECIMENS WELDED WITH TYPE W-21 ELECTRODES

	Failure in Weld	Failure in Cast Steel	Failure in Plate Stock
Maximum, lb. per sq. in...........	..	..	67,100
Minimum, lb. per sq. in...........	..	..	53,400
Average, lb. per sq. in............	..	..	57,640
Per cent Failures to Total Welded.	0	0	100

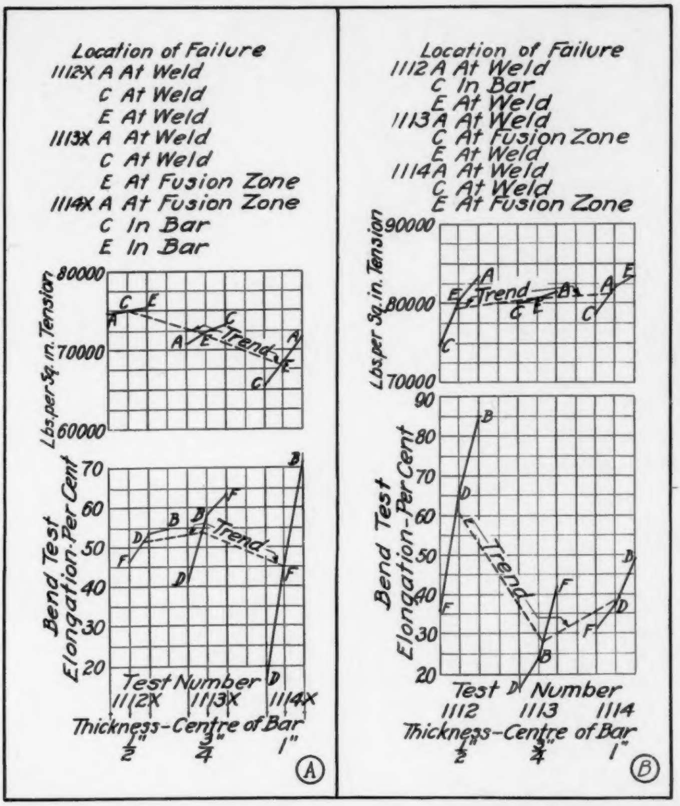

FIG. 5—RESULTS OBTAINED ON MACHINED TENSION AND BEND TEST WELDED SPECIMENS, CAST STEEL TO CAST STEEL, PREPARATION AS RECOMMENDED BY WELDING ENGINEERING DEPARTMENT, GENERAL ELECTRIC CO. AND BY A.S.M.E. BOILER CODE REQUIREMENTS. ALL SPECIMENS ANNEALED AFTER WELDING. (a) SERIES 111, (b) SERIES 111X. (SEE FIGS. 9 AND 11).

Fillet welds may be designed on cast steel and combinations thereof in the same manner as on rolled steel. (See Fig. 4.)

14. Bending tests were influenced by the shape of the junction of the weld and the adjoining rolled or cast surface. The results were relatively uniform regardless of combinations of materials used or method of preparation of surfaces prior to welding. (See Fig. 3.)

15. Fatigue tests indicated an endurance limit of about 20,000 lb. per sq. in. for welds having all surfaces machined. We

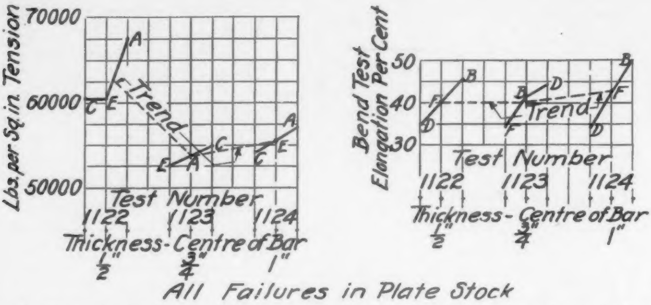

FIG. 6—RESULTS OBTAINED ON MACHINED TENSION AND BEND TEST WELDED SPECIMENS, CAST STEEL TO PLATE STOCK, PREPARATION AS RECOMMENDED BY WELDING ENGINEERING DEPARTMENT, GENERAL ELECTRIC CO. AND BY A.S.M.E. BOILER CODE REQUIREMENTS. ALL SPECIMENS ANNEALED AFTER WELDING. SERIES 112. (SEE FIGS. 9 AND 11.)

were not equipped to make tests of unmachined surfaces. It appears advisable, therefore, to reduce the endurance limit for unmachined structures to not over 12,000 or 15,000 lb. per sq. in. until tests determine a more widely established value, to make allowance for the irregularity of weld surfaces, change in section at points welded, possible incipient cracks due to weld metal overlaps or undercutting and such other factors which may occur in welded joints.

CONCLUSIONS.

16. Cast steel may be welded to cast steel or to rolled steel, either by arc welding with fluxed electrodes or by flash welding, regardless of the character of surface preparation, with entirely satisfactory results.

17. While annealing reduces the tensile strength, it increases ductility, and the best results are obtained when heat treatment is applied after the structure is completely welded.

18. Rather than give details of all the tests, only certain typical ones are given in the following data:

1. Specimens indicated in Tables 5, 6 and 7 and Figs. 2, 3 and 4 were tested without any machining subsequent to welding.

2. Specimens indicated in Figs. 5 and 6 were machined to meet A.S.M.E. Boiler Code requirements.

19. The steel castings used in the unmachined specimens were cast flat with a gate at one end, no risers. Most of the fail-

Table 5

Welding Data on Specimens for Tension Tests

Specimen	Material: Type, Dimensions, in.	Heat Treatment	Welding Technique Data: Electrode Type	Electrode Size, in.	Arc Amps.	Arc Volts	No. of Passes	Layers
Cast Steel Welded to Cast Steel[1]—Arc Welded Butt Welds (Series 23)—Fig. 2a								
232A		None				30	6	4 single
232B	2 C. S. Bars ½ x 3 x 12	None	W-20	3/16	225	34	6	and
232C		Annealed after welding.				30	6	1 double
233A		None	L	3/16	235	24	5	—
233B	2 C. S. Bars ¾ x 3 x 12	None	No record	—	—	—	—	—
233C		Annealed after welding.	L	3/16	235	24	5	—
234A		None		3/16	180—			4 single
234B	2 C. S. Bars 1 x 3 x 12	None	W-21	¼	224	32–38	13	and
234C		Annealed after welding.						3 triple
Cast Steel Welded to Cast Steel[2]—Arc Welded Butt Welds (Series Y21)—Fig. 2b								
Y212A		1 bar annealed before welding.						
Y212B	2 C. S. Bars ½ x 3 x 12	1 bar annealed before welding.	L	3/16	230	23	4	—
Y212C		1 bar annealed before welding. Both annealed after welding.						
Y213A		1 bar annealed before welding.						6 single
Y213B	2 C. S. Bars ¾ x 3 x 12	1 bar annealed before welding.	W-21	3/16—	190—	32–40	12	and
Y213C		1 bar annealed before welding. Both annealed after welding.		¼	250			3 double
Y214A		1 bar annealed before welding.						3 single
Y214B	2 C. S. Bars, 1 x 3 x 12	1 bar annealed before welding.	W-20	3/16	200	32	24	3 double
Y214C		1 bar annealed before welding. Both annealed after welding.						and 5 triple

Preparation of Weld Material

[1]Bevelled edges saw cut back ¼-in. and lower edge ground back to form a vertical shoulder ⅛-in. high.
[2]Bevelled edges cast, then grit blasted and lower edge ground back to form a vertical shoulder ⅛-in. high.

Table 5 (Continued)

WELDING DATA ON SPECIMENS FOR TENSION TESTS

Specimen	Material: Type, Dimensions, in.	Heat Treatment	Welding Technique Data: Electrode Type	Electrode Size, in.	Arc Amps.	Arc Volts	No. of Passes	Layers
Cast Steel Welded to Cast Steel[3]—Flash Welded (Series 51)—Fig. 2c								
512A	2 C. S. Bars ½ x 3 x 12	None	No Data					
512B		None						
512C		Annealed after welding.						
513A	2 C. S. Bars ¾ x 3 x 12	None						
513B		None						
513C		Annealed after welding.						
514A	2 C. S. Bars 1 x 3 x 12	None						
514B		None						
514C		Annealed after welding.						
Cast Steel Welded to Plate Stock[4]—Arc Welded Butt Welds (Series 74)—Fig. 2d								
742A	1 C. S. Bar ½ x 3 x 12 and 1 Plate Stock ½ x 3 x 12	None	L	3/16	235	23	5	—
742B		None						
742C		Annealed after welding.						
743A	1 C. S. Bar ¾ x 3 x 12 and 1 Plate Stock ¾ x 3 x 12	None	W-21	3/16—1/4	190—250	32-40	12	3 single 3 double and 1 triple
743B		None						
743C		Annealed after welding.						
744A	1 C. S. Bar 1 x 3 x 12 and 1 Plate Stock 1 x 3 x 12	None	W-20	3/16	200	32	24	3 single 3 double and 5 triple
744B		None						
744C		Annealed after welding.						

PREPARATION OF WELD MATERIAL

[3]Only preparation was grit blasting.

[4]Cast steel bars, bevelled edges grit blasted and lower edge ground back to form a shoulder 1/8-in. high.
Plate stock bevelled edges gas cut and lower edges ground back to form a shoulder 1/8-in. high.

Table 6

WELDING DATA ON SPECIMENS FOR BENDING TESTS

Specimen	Material: Type, Dimensions, in.	Heat Treatment
Cast Steel Welded to Cast Steel[1]*—Arc Welded Butt Welds (Series Y41)—Fig. 3*		
Y412A		1 bar annealed before welding.
Y412B	2 C.S. Bars ½ x 3 x 12	1 bar annealed before welding.
Y412C		1 bar annealed before welding and specimen "C" annealed after welding.
Y413A		1 bar annealed before welding.
Y413B	2 C.S. Bars ¾ x 3 x 12	1 bar annealed before welding.
Y413C		1 bar annealed before welding and specimen "C" annealed after welding.
Y414A		1 bar annealed before welding.
Y414B	2 C.S. Bars 1 x 3 x 12	1 bar annealed before welding.
Y414C		1 bar annealed before welding and specimen "C" annealed after welding.

	Welding Technique Data					
	Electrode		Arc		No. of	
	Type	Size, in.	Amps.	Volts	Passes	Layers
Y412A						
Y412B	L	3/16	230	20	4	
Y412C						
Y413A						6 single,
Y413B	W-21	3/16-1/4	190-250	32-40	12	3 double
Y413C						
Y414A						3 single,
Y414B	W-20	3/16	200	32	24	3 double and
Y414C						5 triple

PREPARATION OF WELD MATERIAL

[1]Bevelled edges grit blasted and lower edge ground back to form a shoulder ⅛-in. high.

ures that occurred in these cast steel bars showed porosity at the fractures and were considered more unsound than would be experienced in regular practice.

20. The steel castings used in machined specimens were cut from a slab casting which was cast on edge, gated at the bottom and a riser on the upper edge. For instance, the bars marked **1112*A, C, E, B, D*** and ***F,*** (Fig. 8) were cut from a slab 15 x 12 x ⅝-in. at bottom. (Tapered toward upper edge.) The sides were machined to ½-in thick. The slab was then sawed in two, giving two pieces each 15 x 6 x ½-in. The two edges were then machined per regular standard preparation and welded. The welded piece was then annealed, and returned to the machine shop. Pieces were

Table 7

WELDING DATA ON SPECIMENS FOR SHEAR TESTS

Specimen	Material: Type, Dimensions, in.	Heat Treatment	Welding Technique Data: Electrode Type	Electrode Size, in.	Arc Amps.	Arc Volts	No. of Passes	Layers
Cast Steel Welded to Cast Steel[1]—Arc Welded Fillet Welds (Series 31)—Fig. 4a								
31A	2 C.S. Bars $\frac{3}{4}$ x 2 x $4\frac{1}{2}$ and 2 C.S. Bars 1 x 3 x 12	None	L	3/16	235	24	1	
31B			W–21		185	32	2	
31C			W–20		185	32	2	
Cast Steel Welded to Cast Steel[2]—Arc Welded Fillet Welds (Series X31)—Fig. 4a								
X31A	2 C.S. Bars 1 x 3 x 12 and 2 C.S. Bars $\frac{3}{4}$ x 2 x $4\frac{1}{2}$	Annealed before welding	L	3/16	230	20	1	
X31B		Annealed before welding	W–21		200	32	2	
X31C		Annealed before welding and after welding.	W–20		200	32	2	
Cast Steel Welded to Cast Steel[3]—Arc Welded Fillet Welds (Series Y31)—Fig. 4a								
Y31A	2 C.S. Bars 1 x 3 x 12	1 main bar and both cover plates annealed before welding.	L	3/16	230	20	1	
Y31B		1 main bar annealed before welding.	W–21		200	32	2	
Y31C		1 main bar and 1 cover plate annealed before welding. Specimen "C" annealed after welding.	W–20		200			

PREPARATION OF WELD MATERIAL

[1], [2], [3]Surfaces Grit Blasted Only.

Table 7 (Continued)

WELDING DATA ON SPECIMENS FOR SHEAR TESTS

Specimen	Material: Type, Dimensions, in.	Heat Treatment	Welding Technique Data: Electrode Type	Electrode Size, in.	Arc Amps.	Arc Volts	No. of Passes	Layers
Cast Steel Welded to Cast Steel and Plate Stock[4]—Arc Welded Fillet Welds (Series 312)—Fig. 4b								
312A	1 C.S. Bar 1x3x12, 1 Plate Stock 1 x 3 x 12 and 2 C.S. Plates $\frac{3}{4}$ x2 x $4\frac{1}{2}$	None	L	$\frac{3}{16}$	250	20-22	1	1
312B		None	W-21		250	40-42	2	2
312C		None	W-20		240	25	2	2
Cast Steel Welded to Plate Stock[5]—Arc Welded Fillet Welds (Series 313)—Fig. 4b								
313A	1 C.S. Bar 1x3x12, 1 Plate Stock 1 x 3 x 12 and 2 Plate Stocks $\frac{3}{4}$ x 2 x $4\frac{1}{2}$	None	L	$\frac{3}{16}$	240	20-22	1	1
313B		None	W-21		200	40-42	2	2
313C		None	W-20		240	25	2	2

PREPARATION OF WELD MATERIAL

[4]Cast steel main bars and cast steel cover plates, grit blasted. Plate stock main bars gas cut.
[5]Cast steel main bars grit blasted. Plate stock main bars and plate stock cover plates gas cut.

discarded from each end, and the balance sawed into six test bars, alternate bars being used for tension and bending tests. These bars were then machined to meet A.S.M.E. Boiler Code requirements.

21. All specimens of cast steel welded to plate stock failed in plate stock with all types of electrodes. (See Table 4.) The maximum strength of the cast steel is 28 per cent greater than the maximum strength of the plate stock. (See Table 1.) The mini-

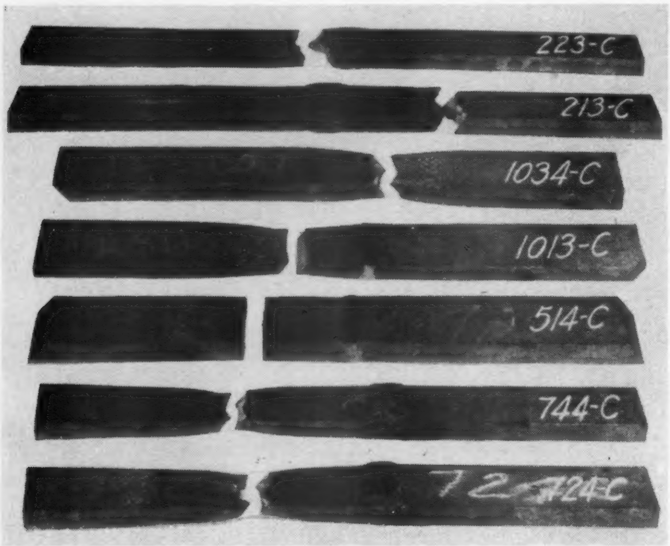

FIG. 7—UNMACHINED TENSION SPECIMENS.

Specimen 223-C—Cast Steel Butt-Welded to Cast Steel, Weld Surfaces Gas Cut, Electrode W-20, Specimen Annealed, Tension Failure Outside of Weld at 76,100 lb. per sq. in.

Specimen 213-C—Cast Steel Butt-Welded to Cast Steel, Weld Surfaces Grit Blasted, Electrode W-21, Specimen Annealed, Tension Failure Outside of Weld at 80,000 lb. per sq. in.

Specimen 1034-C—Cast Steel Flash-Welded to Cold-Rolled Steel, Cast Steel Grit Blasted, Cold-Rolled Steel Cold Sawed, Specimen Annealed, Tension Failure in Cold-Rolled Steel at 64,000 lb. per sq. in.

Specimen 1013-C—Cast Steel Flash-Welded to Plate Stock, Cast Steel Grit Blasted, Plate Stock Gas Cut, Specimen Annealed, Tension Failure in Plate Stock at 57,200 lb. per sq. in.

Specimen 514-C—Cast Steel Flash-Welded to Cast Steel, Cast Steel Grit Blasted, Specimen Annealed, Tension Failure Outside of Weld at 73,100 lb. per sq. in. (See Fig. 2C.)

Specimen 744-C—Cast Steel Butt-Welded to Bar Stock, Bar Stock Gas Cut, Cast Steel Grit Blasted, Electrode W-20, Specimen Annealed, Tension Failure in Bar Stock at 47,900 lb. per sq. in. (See Fig. 2C.)

Specimen 724-C—Cast Steel Butt-Welded to Bar Stock, Weld Surfaces Gas Cut, Electrode W-20, Specimen Annealed, Tension Failure in Bar Stock at 49,000 lb. per sq. in.

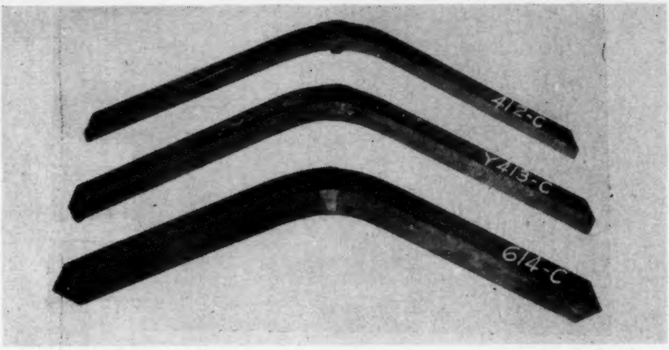

FIG. 8—UNMACHINED BEND TEST SPECIMENS.

Specimen 412-C—Cast Steel Butt-Welded to Cast Steel, Weld Surfaces Grit Blasted, Electrode L, Specimen Annealed, Bending Test Modulus of Rupture 124,600 lb. per sq. in.

Specimen Y413-C—Cast Steel Butt-Welded to Cast Steel, Weld Surfaces Grit Blasted, Electrode W-21, One Bar Annealed, Bending Test Modulus of Rupture 133,000 lb. per sq. in. (See Fig. 3.)

Specimen 614-C—Cast Steel Flash-Welded to Cast Steel, Weld Surfaces Grit Blasted, Specimen Annealed, Bending Test Modulus of Rupture 126,900 lb. per sq. in.

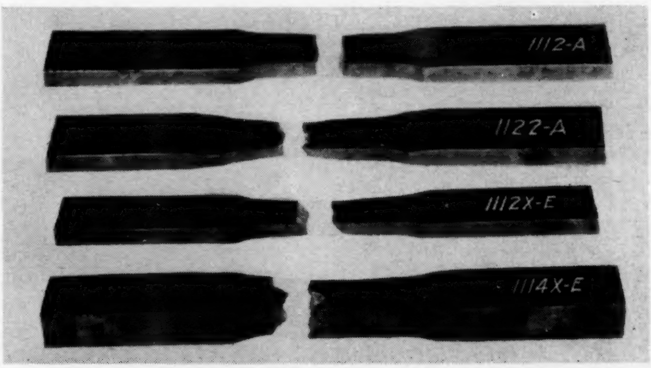

FIG. 9—TENSION TESTS MACHINED IN ACCORDANCE WITH WELDING ENGINEERING DEPARTMENT OF GENERAL ELECTRIC CO. AND A.S.M.E. BOILER CODE.

Specimen 1112-A—Cast Steel Butt-Welded to Cast Steel, Electrode W-21, Specimen Annealed, Tension Failure at 83,700 lb. per sq. in. (See Fig. 5a.)

Specimen 1122-A—Cast Steel Butt-Welded to Plate Stock, Electrode W-21, Specimen Annealed, Tension Failure at 67,100 lb. per sq. in.

Specimen 1112X-E—Cast Steel Butt-Welded to Cast Steel, Deseaming Torch Preparation, Electrode W-21, Specimen Annealed, Tension Failure at 75,200 lb. per sq. in. (See Fig. 5b.)

Specimen 1114X-E—Cast Steel Butt-Welded to Cast Steel, Deseaming Torch Preparation, Electrode W-21, Specimen Annealed, Tension Failure at 68,200 lb. per sq. in. (See Fig. 5b.)

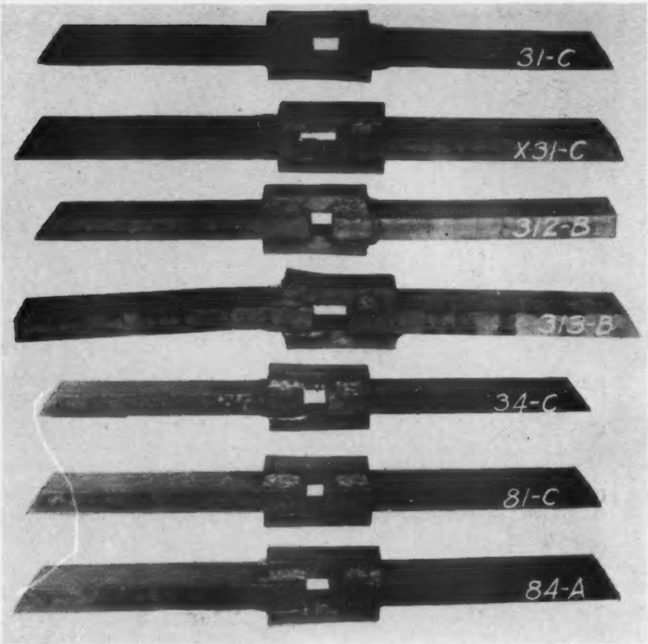

FIG. 10—FILLET WELD TEST SPECIMENS.

Specimen 31-C—Cast Steel to Cast Steel, Weld Surfaces Grit Blasted, Electrode W-20, Specimen Not Annealed, Shear Failure at 15,000 lb. per linear in. on ⅜-in. Fillet Welds.

Specimen X31-C—Cast Steel to Cast Steel, Weld Susfaces Grit Blasted, Electrode W-20, Specimen Annealed, Shear Failure at 9100 lb. per linear in. on ¼-in. Fillet Welds. (See Fig. 4a.)

Specimen 312-B—Cast Steel to Plate Stock, One Main Bar Plate Stock, Electrode W-21, Specimen Annealed, Shear Failure at 12,100 lb. per linear in. on ⅜-in. Fillet Welds. (See Fig. 4b.)

Specimen 313-B—Cast Steel Stock, One Main Bar Cast Steel, Electrode W-21, Specimen Annealed, Shear Failure at 13,750 lb. per linear in. on ⅜-in. Fillet Welds. (See Fig. 4b.)

Specimen 34-C—Cast Steel to Cast Steel, Cover Bars Gas Cut, Electrode W-20, Specimen Not Annealed, Shear Failure 14,600 lb. per linear in. on ⅜-in. Fillet Welds.

Specimen 81-C—Cast Steel to Bar Stock, Cover Bars Bar Stock, Electrode W-20, Specimen Not Annealed, Shear Failure at 10,500 lb. per linear in. on 5/16-in. Fillet Welds.

Specimen 84-A—Cast Steel to Plate Stock, Cover Bars Plate Stock Gas Cut, Electrode L, Specimen Not Annealed, Shear Failure at 12,000 lb. per linear in. on ⅜-in. Fillet Welds.

mum strength of the cast steel is 13 per cent greater than the minimum strength of the plate stock. (See Table 1.) The average strength of the cast steel is 21 per cent greater than the average strength of the plate stock. (See Table 1.) The minimum strength of the cast steel is within 98 per cent of the average strength of the plate stock.

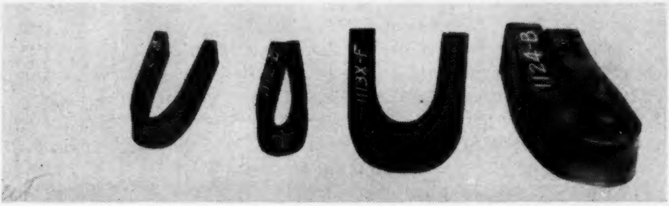

FIG. 11—BEND TEST SPECIMENS MACHINED IN ACCORDANCE WITH WELDING ENGINEERING DEPARTMENT, GENERAL ELECTRIC CO. AND A.S.M.E. BOILER CODE SPECIFICATIONS.

Specimen 1112-B—Cast Steel Butt Welded to Cast Steel, Electrode W-21, Specimen Annealed, Elongation of Weld Metal 85.6 Per Cent. (See Fig. 5a.)

Specimen 1112-D—Cast Steel Butt-Welded to Cast Steel, Electrode W-21, Specimen Annealed, Elongation of Weld Metal 64.4 Per Cent. (See Fig. 5a.)

Specimen 1113X-F—Cast Steel Butt-Welded to Cast Steel, Deseaming Torch Preparation, Electrode W-21, Specimen Annealed, Elongation of Weld Metal 63.9 Per Cent. (See Fig. 5b.)

Specimen 1124-B—Cast Steel Butt-Welded to Plate Stock, Electrode W-21, Specimen Annealed, Elongation of Weld Metal 50.0 Per Cent. (See Fig. 6.)

DISCUSSION

P. E. McKINNEY[1]: There is one thing that is quite impressive in this development and that is the recent trend of foundries to utilize developments in conjunction with the welding art. When weldments first came out, the trend was towards considerable competition between weldments and castings. Many times the man building a weldment attempted to form and simulate a previously cast member, in a most impracticable way, both from the standpoint of cost and utility. Mr. Sampson has shown here that by a combination of cast members and wrought members, we can accomplish the desired end in a much more satisfactory and practicable manner. I think the time is passing when the casting man can say that weldments and welding is not a serious factor to consider as a competing product. However, utilizing the best that is in the casting art and the best that is in the welding art and combining such assemblies as have been shown here, is a real step forward.

I have in mind developments, in the past year or two, on many types of gear boxes where for many purposes, it is necessary to hold weights down. There are some tremendously large gear boxes designed and sent out to foundrymen involving quite a complicated assembly, each end of the boxes having bearing lugs, bosses and other intricate shapes, with the side members simple plates. Now, as a cast member, with those side plate members about ¼-in. thick, it was almost an impossible proposition to produce in the foundry. From a practical engineering standpoint, the end members were the portions of the assembly that took the service stresses. By combining the production of the ends as castings and the side members as wrought plates, it was readily possible to put a highly efficient fillet weld in the corner and give the foundryman something entirely practicable to produce as a flat back. It saved money in the long

[1] Bethlehem Steel Co., Bethlehem, Pa.

run and resulted in a product that did not have to be turned out with any apologies, as in the case of previously produced integral castings.

Now, there are many cases where the practical foundryman can suggest to his customer, in the case of intricate castings, combinations of welding and castings. Likewise, the welding engineer can do the same thing in suggesting that a cast member be introduced instead of attempting to build-up trunnions, bosses and a lot of odd-shaped pieces attached to a flat plate or other wrought members.

It seems to me that this activity that Mr. Sampson has very ably presented is one that can give a lot of food for thought to both foundrymen and welding engineers.

MR. SAMPSON: We have taken the stand that it has seemed to us that the steel foundryman, instead of sitting back and seeing a certain amount of work get away from him, that if he would put on his staff a first-rate welding engineer and have him work in conjunction with their foundry, then when designs came to him for an estimate, he could go back to his possible customer and say, "We believe that we can produce this job more cheaply by splitting that up into component parts, some of which may be cast steel, or they may be all cast steel, or some of them may be welded stock." In other words, personally, if I owned a steel foundry, I do not think I would care a great deal having the floor space, the buildings and the crane equipment, etc., how I got my dividends.

Non-Ferrous Casting Alloys of High Strength*

By A. J. Murphy,** Deptford, London

Abstract

The object of this paper is to demonstrate the wide range of nonferrous casting alloys offering high strength in association with other desirable properties. High strength is a relative term, which has to be considered along with density, electrical and magnetic properties, corrosion-resistance, casting qualities, cost, etc. Manganese bronzes combine strength and hardness with resistance to sea water corrosion and good casting qualities, and are relatively inexpensive. Aluminum bronzes show tensile strength and hardness similar to the manganese bronzes, with higher fatigue strength and generally superior resistance to corrosion, but present greater difficulties in the foundry. The important nickel-base casting alloy is silicon-monel metal. The high melting point raises problems in melting and molding and the intrinsic cost is high, but the high strengths obtainable are combined with outstanding resistance to corrosion, and are also well maintained at high temperatures. The zinc-base alloys are suitable for die casting. Aluminum alloys are used for castings in which high strength is attained by heat treatment. The outstanding alloys in this group are derived from "Y" alloy. The Ceralumin series of alloys in this category gives a range of properties depending upon the type of heat treatment applied. The heat treatment of magnesium alloys is a comparatively recent development, and Elektron alloys "A.8" and "A.Z.91" are discussed in detail. The properties and heat treatments of alloys coming under the above mentioned classes are reviewed.

1. The primary concern of the foundryman is the production of sound castings, and the means adopted to this end are governed ultimately by economic considerations. Foundrymen's technical associations and institutes therefore rightly devote much time to the discussion of those factors in melting, molding, running, sand

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Note: This paper was presented at a session on Nonferrous Founding at the 1935 Convention of A.F.A. in Toronto, Canada.

control, etc. which affect the quality and cost of castings. Constant attention to these points is necessary if castings are to retain their position in the face of competition from the different application of forgings and fabricated construction, not to mention non-metallic molded products.

2. The adaptability of the casting process which permits its application to the economical production of the most involved shapes will always remain a forceful argument in its favor, but there is nevertheless more than a tendency for the advocate of castings to be driven into a purely defensive attitude. It is well, therefore, for foundrymen to consider from time to time how wide is the range of work which they as a body can undertake. In particular it may be useful to consider what is the scope of the materials to which they can apply their art and science, and the present opportunity appears to be suitable for discussing the subject with reference to the mechanical properties of non-ferrous casting alloys.

3. High strength is a purely relative term, and the significance of a numerical value of, say, tensile strength is not defined until information is available regarding the other properties of the material and the conditions under which it is required to operate. A simple but important example of this is seen in the relation between strength and specific gravity, which in aeronautical engineering makes a casting of an aluminum alloy with a tensile strength of 55,000 lbs. per sq. in. more useful than a wrought steel which has a tensile strength of 90,000 lbs. per sq. in., but which has a specific gravity three times greater than that of the aluminum alloy.

4. In other cases electrical conductivity, corrosion resistance, machinability and even cost replace specific gravity as the attribute in relation to which strength has to be considered. The metallurgist who has to give attention to these factors in connection with foundry products required in the aeronautical, automobile, marine, railway, chemical, electrical and general engineering industries soon comes to appreciate the versatility of the non-ferrous casting alloys as a group. It is desirable to emphasize here that the present discussion is concerned only with casting alloys.

5. By far the larger proportion of the data available on strong non-ferrous alloys, especially those published during recent years, refers to these materials in the wrought form; not only is it generally impossible to deduce from such information what

mechanical properties are likely to be obtained from alloys of the same composition in the cast condition, but it is often found that alloys which have outstanding properties when worked appropriately are only of mediocre value as castings.

6. Instances of striking mechanical strength are encountered among cast alloys having as their bases, respectively, copper, nickel, zinc, aluminum and magnesium. These alloys can be classified in two groups, according as the high strength is realized in the "as cast" condition or is attained by subsequent heat-treatment.

7. The best known copper-base alloys coming within the subject of this paper are the manganese bronzes and aluminum bronzes. If the term "bronze" is defined as indicating essentially an alloy of copper and tin it is not strictly applicable to either of these materials: the first should therefore be described as high-tensile brass and the second as copper-aluminum. In both cases, however, the term bronze is applied so commonly in commercial practice that there is little risk of it being misunderstood in this connection.

MANGANESE BRONZE

8. The manganese bronzes used for castings are derived from the well-known brass containing 60 per cent copper and 40 per cent zinc, by alloying with these metals manganese, iron, aluminum, tin and nickel. All these five additional elements are rarely found together: iron in amounts from 1 to 2 per cent is almost always present, the tin content does not change much from 1 per cent, manganese may vary from as little as 0.1 per cent to 5 per cent, aluminum from 0.1 per cent to 5 per cent, and nickel from 1 to 2 per cent. Among the normal casting alloys, which all contain iron as previously mentioned, those having a tin content of 1 per cent generally have low aluminum and manganese contents, and those containing nickel have a very low percentage of aluminum.

9. Two principal factors govern the mechanical properties of cast manganese bronzes; these are the microstructure and the chemical composition. The most useful bronzes are those having an alpha-beta or a beta structure. Guillet's list of "zinc equivalence" factors shown in Table 1 is now well known. This ascribes certain numerical values to each of the addition metals to denote their quantitative effect, in terms of equivalent proportions of zinc, on the relative volumes of alpha and beta phases in a man-

Table 1

ZINC EQUIVALENT FACTORS (GUILLET)

Metal	Zinc equivalent.
Aluminum	6.0
Tin	2.0
Iron	0.9
Manganese	0.5
(Nickel)	(1.1 parts copper)

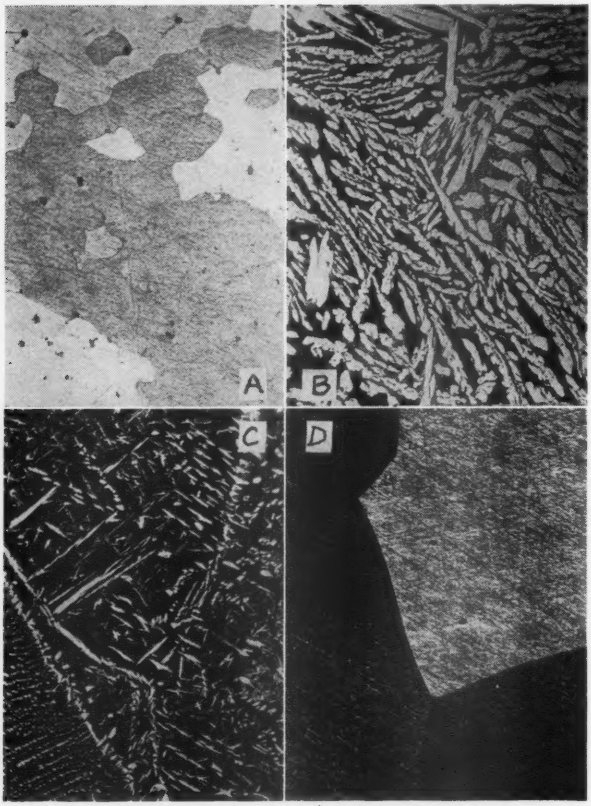

FIG. 1—MICROSTRUCTURE OF PLAIN BRASSES SHOWING ALPHA AND BETA STRUCTURE, x 50 (REDUCED ½ SIZE IN PRINTING).

(A) ZINC 33.7 PER CENT. ALL ALPHA.
(B) ZINC 41.8 PER CENT. ALPHA 55 PER CENT, BETA 45 PER CENT.
(C) ZINC 43.7 PER CENT. ALPHA 14 PER CENT, BETA 86 PER CENT.
(D) ZINC 45.5 PER CENT. ALL BETA.

ganese bronze. In practice these factors are found to operate with good accuracy so long as the particular element considered is not present in amounts greater than about 2 per cent.

10. It is well to remember that Guillet's rule is only an attempt to express in a simple manner the relations existing between the phases-fields in a ternary, quarternary or even more complex diagram of equilibrium constitution. The factor for assessing each metal in its zinc equivalence can only have a constant value so long as the boundaries between the alpha, alpha-beta and beta phase fields in the ternary diagram are straight lines and remain parallel.

11. The transition from the all alpha structure to the all beta takes place in the sand cast plain copper-zinc alloys over the range of zinc contents from 34 to 45 per cent. Table 2 shows the progressive change in mechanical properties over this range of composition in sand-cast test-bars of the "straight" copper-zinc alloys. In Fig. 1 are shown photomicrographs illustrating the sequence of changes in the microstructure of sand-cast test-bars. It is of interest to compare these results with those observed in a

Table 2

MECHANICAL PROPERTIES OF COPPER-ZINC ALLOYS, SAND CAST

Zinc per cent	Alpha phase, per cent	Maximum Stress, lbs. per sq. in.	Elongation on 2 inches. per cent	Brinell Hardness.
33.7	100	33,600	63	55
35.0	88	42,800	59	59
38.0	75	47,152	56	64
40.1	69	51,520	55	72
41.8	55	55,104	50	80
43.7	14	62,272	27	102
45.5	0	68,096	27	105

Table 3

MECHANICAL PROPERTIES OF MANGANESE BRONZE, SAND CAST

Zinc per cent	Alpha phase, per cent	Maximum Stress, lbs. per sq. in.	Elongation per cent on 2 inches.	Brinell Hardness.
31.0	100	46,592	24	72
32.9	78	53,312	36	75
37.5	70	60,928	50	85
39.2	45	69,216	42	95
41.1	25	76,608	28	121
44.1	0	83,328	21	129
47.8	0 (Delta present)	54,656	4	138

manganese bronze containing, besides copper and zinc, iron 1 per cent, tin 1 per cent, aluminum 0.25 per cent, and manganese 0.25 per cent. The numerical data are given in Table 3, and the corresponding photomicrographs of Fig. 2.

12. Just as in the plain copper-zinc alloys, the increase of zinc content in manganese bronze, which diminishes the proportion

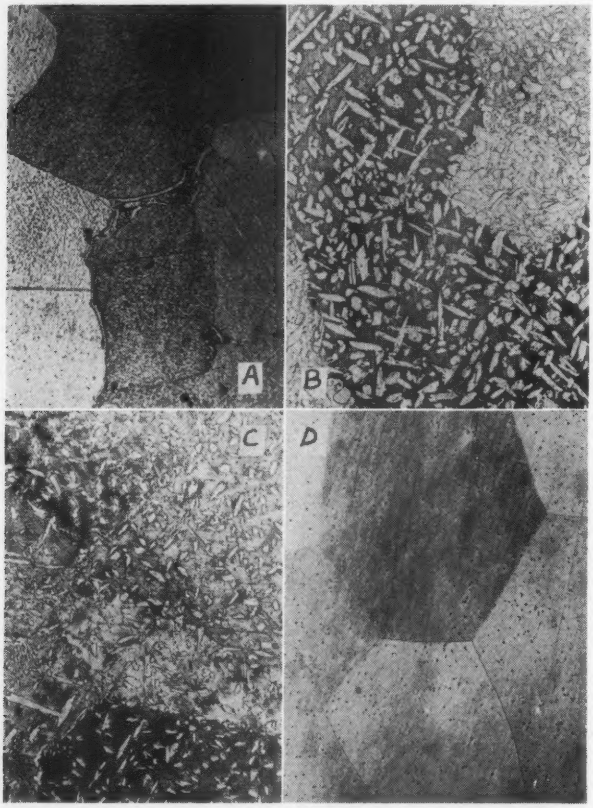

FIG. 2—MICROSTRUCTURE OF MANGANESE BRONZES SHOWING ALPHA AND BETA STRUCTURE, x 50 (REDUCED ½ SIZE IN PRINTING).

(A) ZINC 31 PER CENT. ALPHA WITH COPPER-TIN EUTECTOID AT GRAIN BOUNDARIES.
(B) ZINC 39.2 PER CENT. ALPHA 45 PER CENT, REMAINDER BETA, WITH FINELY DISPERSED HARDENING CONSTITUENT.
(C) ZINC 41.1 PER CENT. ALPHA 25 PER CENT, REMAINDER BETA, WITH FINELY DISPERSED HARDENING CONSTITUENT.
(D) ZINC 44.1 PER CENT. BETA, WITH FINELY DISPERSED HARDENING CONSTITUENT.

of the alpha constituent, causes a progressive increase in hardness and also in tensile strength until a wholly beta microstructure is attained. Other details in Table 3, however, illustrate the greater complexity of manganese bronzes: as an example, it is seen that in the particular bronze considered, unlike the copper-zinc series, absence of the beta constituent does not correspond to the maximum ductility. This is due to the appearance in the copper-rich members of the series of the brittle eutectoid constituent of the copper-tin alloys. This is clearly seen in A of Fig. 2. It should also be noted that 1 per cent of iron in the bronze is sufficient to cause the appearance in all the alloys of a third, so called "hardening", constituent.

Control of Composition

13. The rapid change in properties accompanying a variation in the proportions of the alpha and beta constituents in manganese bronze obviously necessitates careful control of composition. The best practice in founding manganese bronze is to use previously made ingot metal, and if this is done there is no appreciable change in the contents of the addition metals iron, manganese, tin, etc. on remelting. Attention need only be concentrated on the zinc content and in crucible melting under reasonable control the loss of zinc is generally sufficiently uniform and consistent to permit a suitable allowance for this to be made in the original manufacture of the ingot.

14. In air furnace melting, such as is used for castings weighing some tons, the loss of zinc is less predictable, and must be corrected by the addition of spelter before casting. Fortunately a rapid means of estimating the zinc content in most manganese bronzes is available in the examination of the fracture of sample chill bars. Using this method an experienced operator can judge when the correct composition is attained to an accuracy of ± 0.5 per cent zinc.

Mechanical Properties

15. The mechanical properties obtained in sand-castings of manganese bronzes having an alpha-beta microstructure are:

Yield point........34,000 to 50,000 lbs. per sq. in.
Maximum stress....67,000 to 90,000 lbs. per sq. in.
Elongation on 2 in...............35 to 15 per cent
Brinell hardness (10/3000/15)..........100 to 180

Foundry Technique

16. It is not proposed to discuss in detail the foundry technique, but it may be mentioned that the patternmaker's contraction is rather high (1/8 to 3/16 in. per foot, according to the type of casting), and the shrinkage on solidification is high. Special attention has to be devoted to providing for the high shrinkage by adequate risers, and care must be taken to insure non-turbulent entry of the metal into the mold. In general principles the foundry technique for manganese bronzes resembles that for aluminum

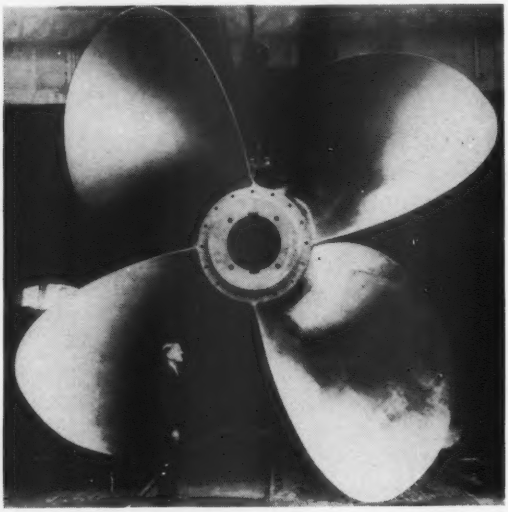

FIG. 3.—MANGANESE BRONZE PROPELLER CASTING FOR "QUEEN MARY," FINISHED WEIGHT 78,400 LBS.

bronzes, but the difficulties are definitely not so great as in the latter case.

Examples of Application of Manganese Bronze Castings—Alpha—Beta

17. The applications of alpha-beta manganese bronze castings are very numerous. No doubt the best known example is that of marine propellers, the casting weights of which may vary from about 40 lbs. for propellers of small yachts to over 118,000 lbs. for those of the Cunarder "Queen Mary". Fig. 3 shows one

of those propellers, and Fig. 4 one from the "Normandie", the finished weights in the two cases being 78,400 lbs. and 52,080 lbs. respectively.

18. The example of marine propellers indicates the suitability of alpha-beta manganese bronzes for parts which are highly stressed and exposed to seawater. At the same time, care has to be taken, in marine applications, to guard against abnormally

FIG. 4—MANGANESE BRONZE PROPELLER CASTING FOR THE "NORMANDIE," FINISHED WEIGHT 52,080 LBS.

corrosive conditions, such as are developed by galvanic action due to the proximity of large masses of copper, as in copper-sheathed hulls.

19. For land use the manganese bronzes find application on account of their strength, resistance to corrosion and non-magnetic properties. Examples are provided by various ordnance parts such as gun mountings and races, rotor end caps and rings in turbo-electric generators.

20. Manganese bronze often proves its value in an emergency when a forged or cast steel part has to be replaced at short notice. The fact that a bronze casting having equivalent strength can be produced at very short notice is not so widely appreciated by engineers as it might be. No heat-treatment after casting is required to attain the mechanical properties previously quoted for manganese bronze.

Beta Manganese Bronze

21. Special mention should be made of the beta manganese bronzes. In normal sand castings of this type of alloy a tensile strength as high as 112,000 lbs. per sq. in., with an elongation of 15 to 20 per cent can be obtained. Castings having properties such as these are obviously attractive for many purposes, and they are in fact giving satisfactory service in applications where non-magnetic properties and a capacity to withstand high centrifugal stresses are required. Caution is necessary, however, in using beta manganese bronzes for castings which may be exposed to corrosive conditions, and when the beta bronze contains aluminum it should not be adopted for parts subjected to stress while in contact with seawater, saline, ammoniacal or acid solutions. Under these conditions the aluminum-bearing beta manganese bronzes are liable to an insidious form of intercrystalline cracking.

ALUMINUM BRONZE

22. The writer has the impression that the second group of high-strength copper-base alloys, the aluminum bronzes, has received more attention in recent years in America than in Great Britain, at least as regards their application as sand castings. The sole reason for this apparent neglect is the rather formidable difficulty in foundry technique which they present and which effectively discourages the foundryman who, accustomed to the methods suitable for molding and casting in brass and gunmetal, attempts to deal with aluminum bronze in the same way.

23. It is unnecessary on this occasion to enlarge on the methods which have to be adopted for the successful production of aluminum bronze castings. It will suffice to say that the fundamental causes of the casting difficulties are, first, the great change in volume when the liquid bronze solidifies and the narrow range of temperature over which solidification occurs, and secondly, the high reactivity of the aluminum in the molten bronze towards

oxygen and steam, and the tenacious character of the oxide films produced. The first feature demands special attention in the provision of adequate risers and chilling, while the second calls for special care in avoiding turbulence in the entry of the metal into the mold. It is in the latter direction that the foundryman's ingenuity is most severely taxed.

24. It is sometimes said that the aluminum founder takes more kindly than the brass-founder to casting aluminum bronze, and while it is true that many of the methods required are more akin to those adopted in handling the light alloys of aluminum, the higher casting temperatures of aluminum bronze aggravate considerably the troubles which arise from oxide formation. The large volume of vapor generated at these temperatures in a sand mold, even when it has previously been stove-dried, not only causes marked turbulence in the incoming metal, but also multiplies the opportunities for oxide formation. The absence of this factor in die-casting goes far to explain the greater ease with which clean castings of aluminum bronze can be made in permanent molds as compared with sand molds; it also emphasizes the necessity for free venting and the use of sand of high permeability.

Properties of Aluminum Bronzes

25. Normal values of tensile strength in aluminum bronze sand castings are from 67,000 to 100,000 lbs. per sq. in. In the plain copper-aluminum alloys the compositions used for sand casting are generally restricted to the range 8 to 10 per cent aluminum, the corresponding range of mechanical properties in the sand cast condition being:

Maximum stress.....56,000 to 71,600 per sq. in.
Elongation on 2 inches.......60 to 25 per cent.
Brinell Hardness...................70 to 100.

26. As sand-cast in a section of about 1 inch thickness the alloy with 8 per cent aluminum has a wholly alpha microstructure and with 10 per cent aluminum consists of practically equal proportions of the alpha and beta phases. The limits of mechanical properties mentioned correspond to these two compositions. In passing it is interesting to compare these data with the corresponding values in the plain copper-zinc alloys. When the microstruc-

ture is just completely within the alpha range, the approximate figures for sand cast 1 in. diameter bars are:

	Maximum stress, lbs. per sq. in.	Per cent Elongation in 2 ins.	Brinell Hardness.
Copper-aluminum	56,000	60	65
Copper-zinc	33,600	65	50

27. In the alloys containing approximately equal proportions of the alpha and beta phases the corresponding values are:

	Maximum stress, lbs. per sq. in.	Per cent Elongation in 2 ins.	Brinell Hardness.
Copper-aluminum	71,600	22.0	95
Copper-zinc	56,000	50.0	80

Self Annealing

28. It is evident that in alloys of similar constitution the aluminum bronzes are intrinsically stronger than the copper-zinc alloys. The plain copper-aluminum alloys, however, are prone to a disability from which the brasses are free, namely, "self-annealing". This is a type of embrittlement which is liable to occur when the alloy cools slowly through the range of temperature in which the transformation of the beta phase to alpha-delta occurs. In equilibrium the temperature of this change is at 1004 degrees Fahr. (540 degrees Cent.), and in sand castings of heavy section it is difficult to ensure rapid cooling at this temperature.

29. Various devices can be adopted to avoid self-annealing, such as the use of local chills, knocking out castings from the mold at a high temperature, or the castings can be reheated above the transformation temperature, quenched and tempered. A much simpler remedy, however, is to use a ternary or quarternary alloy, containing iron, or iron and nickel, and the plain copper-aluminum alloys are now largely replaced by those containing up to 5 per cent each of these additional metals.

30. The effect of these additions on the constitution of the copper-aluminum alloys has not been thoroughly investigated, and it is not certain whether iron, for example, eliminates the eutectoid transformation of the beta phase under equilibrium conditions, or merely so reduces the rate of transformation that no appreciable amount of embrittling delta constituent is formed even with slow

Table 4

EFFECT OF VARIATIONS IN ALUMINUM CONTENT ON PROPERTIES OF SAND CAST ALLOYS OF TERNARY ALUMINUM BRONZE TYPE

Aluminum per cent	Alpha per cent	Maximum Stress, lbs. per sq. in.	Elongation in 2 inches. per cent	Brinell Hardness
6.02	100	72,128	52	103
8.42	50	79,744	48	111
10.12	10	90,596	28	137
12.20	Trace	83,776	3	217
13.60	(delta present)	42,112	1	277
16.0	(delta present)	......	..	363

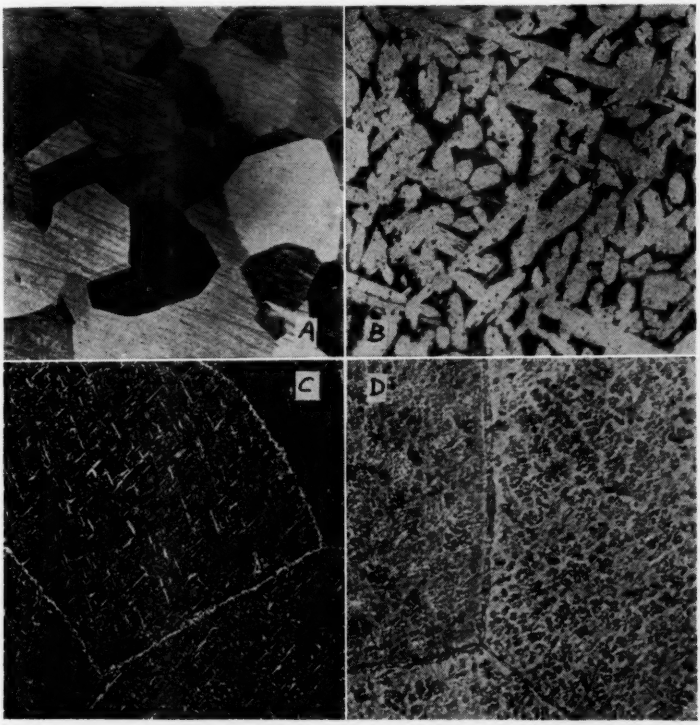

FIG. 5—MICROSTRUCTURE OF ALUMINUM BRONZE SHOWING ALPHA AND BETA CONSTITUENTS (REDUCED ½ SIZE IN PRINTING).

(A) ALUMINUM 6 PER CENT. ALL ALPHA. ORIGINAL x 100.
(B) ALUMINUM 8.4 PER CENT. ALPHA 50 PER CENT, REMAINDER BETA, WITH TERNARY CONSTITUENT. ORIGINAL x 150.
(C) ALUMINUM 12.2 PER CENT. BETA WITH TRACE OF ALPHA AND TERNARY CONSTITUENT. ORIGINAL x 200.
(D) ALUMINUM 13.6 PER CENT, BETA, DELTA AND TERNARY CONSTITUENT. ORIGINAL x 200.

rates of cooling. In any event, the practical effect of the iron is to suppress self-annealing even in heavy castings produced under normal conditions.

31. A typical example of the ternary aluminum bronzes has an iron content of 3 per cent, and Table 4 gives an idea of the effect of variations in aluminum content on the microstructure and mechanical properties of the sand cast alloys, while Fig. 5 shows characteristic microstructures in this range.

32. The most useful alloys in this series are those containing from 8 to 10 per cent aluminum, and the relation to the plain copper-aluminum alloys is analogous to that between the manganese bronzes and the simple brasses. It is noticeable, however, that in the aluminum bronzes the increased strength for a given proportion of alpha and beta phases resulting from the addition of 3 per cent iron is accompanied by an increase in ductility.

33. By the addition of nickel as well as iron, still further improvements in strength are obtainable. As an example of this class of aluminum bronze may be mentioned Superston L. 189 bronze, which contains approximately 5 per cent each of iron and nickel, and has the following properties when sand-cast:

Maximum Stress	94,000 to 100,000 lbs. per sq. in.
Yield point	49,300 lbs. per sq. in.
Elongation on 2 inches	15 per cent.
Brinell hardness	160-190

34. The outstanding differences between aluminum bronzes and manganese bronzes, apart from founding properties, are seen in the fatigue strength and the behavior in corrosive environments. In general it is found that the safe range of stress under fatigue is considerably greater in aluminum bronze than in a manganese bronze of equal tensile strength. Superston L. 189 bronze, with a tensile strength of 94,000 to 100,000 lbs. per sq. in., has a fatigue strength of $\pm 33,600$ lbs. per sq. in. on a basis of 20,000,000 reversals, whereas in Superston Fifty, a manganese bronze having a tensile strength of 112,000 lbs. per sq. in., the fatigue strength on the same basis is $\pm 21,300$ lbs. per sq. in.

Some Application of Aluminum Bronzes

35. The excellent resistance to corrosion by seawater, mineral acids in moderate dilution, acid vapors and numerous chemical reagents accounts for many of the applications of aluminum

bronzes. An interesting feature of these bronzes is their ability to resist electrolytic, or galvanic, corrosion when in contact with copper in saline solutions. In this property, which is no doubt due to the formation of a protective film having aluminum oxide or hydroxide as a basis, aluminum bronzes show a marked superiority over manganese bronzes.

36. The combination of high strength with very useful corrosion-resisting properties allows aluminum bronze castings to be used for such parts as cradles, crates, racks and hooks in steel-pickling plant, components of valves handling brines and acidic liquors, fan blades exposed to acid vapors, and stressed parts such as gearwheels liable to be immersed in seawater. Fig. 6 shows a pickling crate made of aluminum bronze, the base being a casting of Superston L. 189 bronze. Even where corrosion is not involved, the hardness and strength of aluminum bronze castings justify

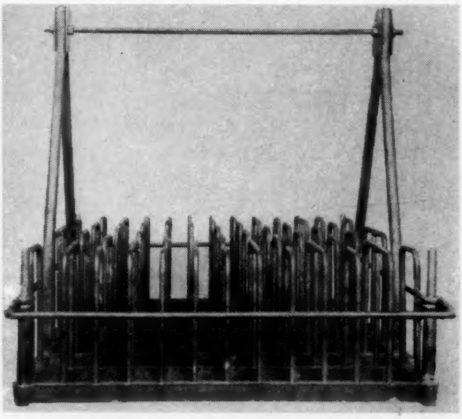

FIG. 6—PICKLING CRATE OF ALUMINUM BRONZE, SUPERSTON L. 189.

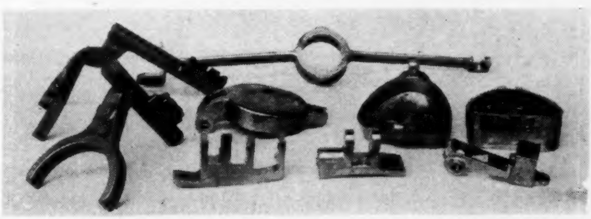

FIG. 7—DIE CASTINGS OF ALUMINUM BRONZE.

their application, as for example, in worm-wheels, die-cast levers and striking forks of automobile gear-boxes, and certain types of engine cylinder heads. Typical die-castings in aluminum bronze are shown in Fig. 7.

37. In order to preserve a true balance in the inevitable comparison of aluminum bronzes with manganese bronzes, it is necessary to emphasize the advantage which the latter possess in ease of casting. This consideration is often sufficient to turn the scale in favor of the manganese bronze in cases of complicated castings, even when aluminum bronze would be preferred on its general properties.

NICKEL ALLOYS

38. The strong nickel-base alloys which lend themselves most readily to casting in sand molds are Monel metal and Silicon-Monel containing approximately 65 per cent nickel, nickel-copper-tin alloys with 40 to 50 per cent of nickel, copper-nickel-iron alloys with 30 per cent nickel, and the nickel-chromium and nickel-chromium-iron alloys of the "Cronite" type. In all these the strength at the ordinary temperature does not surpass that obtainable in manganese bronzes and aluminum bronzes, but their retention of strength at high temperature and their outstanding corrosion resistance frequently justify their high intrinsic cost in special applications.

High Melting Point.

39. Owing to the high melting point, approximately 2462 degrees Fahr. (1350 degrees Cent.), the melting and casting of Monel metal involve rather different procedure from the normal practice with bronze. In the author's experience melts up to 600 lbs. weight can be handled successfully in graphite crucibles in oil-fired tilting furnaces. With an efficient furnace, the pouring temperature required—2642 to 2822 degrees Fahr. (1450 to 1550 degrees Cent.)—is readily attained, and in fact it is found, rather paradoxically, that the chief danger to be guarded against is a tendency to cast at too high a temperature through over-anxiety to avoid "cold" metal.

40. Excessive pouring temperature can produce castings with an open, non-coherent texture, containing brightly facetted crystals which suggest that serious contamination with carbon has occurred, although in fact this appearance is actually due to se-

vere shrinkage effects. This is confirmed by the fact that such defective material, on remelting and casting at the correct temperature gives perfectly satisfactory castings. In all cases the use of a manganese dioxide flux and the addition of a small amount of magnesium before casting is advisable, in order to eliminate oxides and sulphides of nickel. A refractory sand, generally oil bonded, is usually to be recommended for the molds.

Compositions and Properties.

41. A typical composition of normal Monel metal is:

Nickel	67 per cent	Manganese	1 per cent
Copper	29 per cent	Silicon	1 per cent
Iron	2 per cent	Carbon	Up to 0.2 per cent

and sand castings show mechanical properties as follows:

Tensile strength—53,700 to 76,200 lbs. per sq. in.
Yield point—21,360 to 40,300 lbs. per sq. in.
Elongation on 2 inches—15 to 30 per cent.
Brinell Hardness—120-160.

42. The addition of silicon causes a marked improvement in the casting properties of Monel metal. Increased strength and hardness, at the expense of a loss of ductility also result from this modification in composition, as shown by the following values:

	2.5 to 3.0 per cent silicon.	3.5 to 4.0 per cent silicon.
Tensile Strength	85,120 lbs. per sq. in.	100,800 lbs. per sq. in.
Yield point	51,520 lbs. per sq. in.	89,600 lbs. per sq. in.
Elongation on 2 inches, per cent	16	5
Brinell hardness	210	270

43. Both forms of Silicon-Monel metal are amenable to heat-treatment. Heating to 1652 degrees Fahr. (900 degrees. Cent.) and quenching in water softens the alloys, which can be hardened by tempering at 1112 degrees Fahr. (600 degrees Cent.) for four hours. By this treatment a hardness as high as 370 can be attained with the higher silicon content.

Application.

44. Sand castings in Silicon-Monel metal find application in chemical plant handling mineral acids and alkalies, in valves and

nozzles exposed to superheated steam, and generally where high strength with resistance to corrosion and erosion are desired. Fig. 8 shows a valve cage which operates in superheated steam in a turbine installation.

45. Nickel-copper-tin alloys present a useful combination of strength, hardness, reasonable bearing properties, strength at elevated temperatures and resistance to corrosion, which make them suitable for parts of steam valves and for rubbing surfaces in pumps dealing with corrosive liquids. The alloy containing nickel 50 per cent, copper 40 per cent and tin 10 per cent has the following properties at various temperatures as shown in Table 5.

Effects of Silicon Additions.

46. As in the case of Monel metal, by the addition of silicon to nickel-copper-tin alloys, it is possible to obtain a marked increase in hardness. For instance, an alloy containing 60 nickel, 28 copper, 12 tin, has a hardness of approximately 159 brinell as cast. By the addition of 1 per cent silicon this can be increased to about 190 brinell, with 2 per cent silicon to 260 brinell, and with 3 per cent silicon to 350 brinell.

47. With these silicon additions, it is also possible to make a

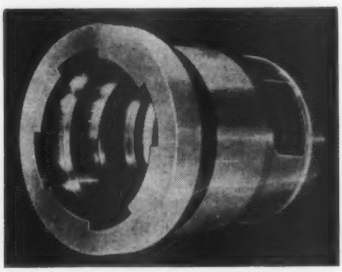

FIG. 8—VALVE CAGE FOR SUPERHEATED STEAM OF SILICON-MONEL METAL.

Table 5

PROPERTIES AT VARIOUS TEMPERATURES OF A NICKEL-COPPER-TIN ALLOY

Temperature of Test		Maximum Stress, lbs. per sq. in.	Elongation in 2 inches. per cent
Deg. C.	Deg. F.		
Room	Room	85,120	0.5
400	750	72,800	1.0
480	900	60,480	1.0
540	1,000	50,400	1.0
590	1,100	43,008	1.0

reduction in the tin content, and still retain hardness; thus, an alloy containing 67 per cent nickel, 30 per cent copper, 3 per cent tin, has a hardness of about 112 brinell. With the addition of 2 per cent silicon, a hardness of 157 brinell is obtained, whereas with 4 per cent of silicon the hardness is increased to about 377 brinell.

Zinc Alloys

48. Brief reference is made to the zinc-base die-casting alloys because they present an example of high strength and hardness in relation to the ease with which die-castings of great accuracy can be produced and the low intrinsic cost of the basic metal. The alloys of this class in use today represent an enormous advance on the earlier zinc alloys, which were liable to distressing failure through structural and dimensional instability, especially when exposed to moist atmospheres. The improvement which has been achieved has only been made possible by the progressive increase in the purity of the zinc obtainable, metal with a purity of 99.99 per cent being in commercial use today, but metallurgical investigation has also shown that the mechanical properties of the zinc-copper-aluminum series are much superior to those of the zinc-copper-tin alloys formerly employed, although the latter still have the advantage of being more easily soldered, on account of the absence of aluminum. In the alloys containing copper and aluminum, the presence of 0.1 per cent magnesium is found to improve the resistance to intercrystalline corrosion, but neither the tin nor the lead content must exceed 0.01 per cent, otherwise serious brittleness results.

Properties.

49. In alloys having as a typical composition:

Copper	3 per cent
Aluminum	4 per cent
Magnesium	0.1 per cent
Zinc	Remainder,

tensile strengths as high as 49,000 lbs. per sq. in. are obtained in die-cast test-pieces. The brinell hardness is approximately 80, and while the elongation rarely exceeds 5 per cent, the alloys have the peculiar property of being able to undergo remarkable deformation in torsion before fracture. Since the high-speed production required in the manufacture of zinc-base die-castings requires them

to be ejected from the die immediately after solidification it is important that they should be as free as possible from hot-shortness, and the alloys of later origin are very satisfactory in this respect.

Applications.

50. The enormous variety of applications of zinc-base die-castings precludes any attempt to give a list of representative examples. Parts which illustrate their use on account of good

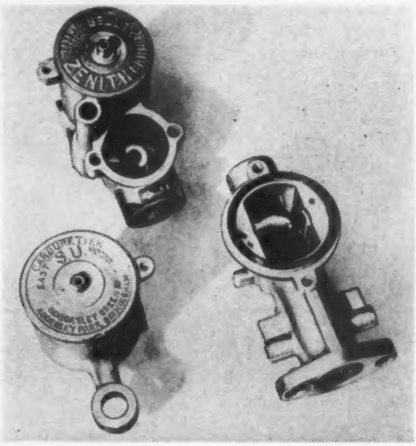

FIG. 9—DIE-CAST CARBURETOR BODIES OF ZINC-BASE ALLOY, MAZAK.

mechanical properties are carburetor bodies, as shown in Fig. 9, parts of pneumatic chippers and even golf club heads.

ALUMINUM ALLOYS.

51. The two classes of nonferrous casting alloys remaining to be considered are the light alloys of aluminum and magnesium. In both these important series high strength, in the sense in which that term is used in the present discussion, is realized as the result of heat-treatment.

52. The numerous publications of the last few years have provided a large amount of information on the casting, mechanical properties and applications of strong aluminum alloys. It is only proposed on the present occasion, therefore, to consider a few examples of casting alloys with which the author has been con-

cerned recently, namely, "Y" alloy and the Ceralumin series of alloys.

"Y" Alloy.

53. "Y" alloy is of special interest because its development marked the inception of a new class of aluminum alloys characterized by high strength and hardness, produced by heat-treatment and retained in a high degree at elevated temperatures. It represented the culmination of wartime investigations to establish an improved light alloy for the pistons of aero-engines, and the success with which this object was attained may be judged from the extensive use which it now enjoys for pistons of all types of internal combustion engines.

54. The nominal composition of "Y" alloy is:

Copper	4.0 per cent
Nickel	2.0 per cent
Magnesium	1.5 per cent
Aluminum	Remainder,

and the specific gravity 2.8.

55. The heat-treatment applied to "Y" alloy consists of a "solution" stage in which the castings are heated to a temperature of 932 to 968 degrees Fahr. (500 to 520 degrees Cent.) for a period of 6 to 20 hours, dependent on the section, quenched in oil, cold or hot water, and an "ageing" stage in which they are allowed to rest at the room temperature for five days.

56. "Y" alloy is far from being the easiest aluminum alloy to handle in the foundry. The relatively high magnesium content increases the tendency for the formation of a tenacious oxide skin on the surface of the molten metal, and this skin gives rise to dirty patches in the casting if turbulence in the mold is not avoided. A second factor which has to be contended with is the large change of volume on solidification, which calls for much more generous risers than are necessary for the simple alloys of aluminum with copper, copper and zinc, or silicon. As regards its tendency to show "pinholing" due to the release during solidification or previously absorbed gas, "Y" alloy is less troublesome than aluminum-silicon alloys, but more susceptible than, for example, aluminum-copper-zinc alloys. The very fact that the liability to these troubles is known, and that their effects are readily recognized, simplifies the task of the foundrymen in dealing with

them, and it is rarely that they cannot be overcome by the systematic application of fundamental principles.

57. In the majority of the important castings made in "Y" alloy permanent metal molds or sand molds with numerous built in chills are employed, and it is appropriate therefore to consider in greatest detail the mechanical properties realized in test-bars cast in metal molds and subsequently heat-treated. In this condition the following are typical of the properties obtained:

Maximum stress, 40,300 to 44,800 lbs. per sq. in.
0.1 per cent proof stress, 31,360 lbs. per sq. in.
Elongation on 2 inches, 2 to 4 per cent.
Brinell hardness number 105.

58. In sand cast bars of 1 in. diameter, heat-treated, a maximum stress of not less than 31,360 lbs. per square inch is required by specification L.35 for aircraft material, and a 0.1 per cent proof stress of not less than 29,100 lbs. per sq. in. can be expected.

59. The strength of "Y" alloy at elevated temperatures is indicated by the following results of "short time" tensile tests on chill cast specimens:

Temperature		
Degrees Fahr.	Degrees Cent.	Strength, lbs. per sq. in.
212	100	44,800
392	200	38,080
482	250	37,290
572	300	35,840
662	350	26,880

Figs. 10A and B show the microstructures of "Y" alloy in the untreated sand cast condition, and after heat-treatment.

Ceralumin Series of Aluminum Alloys.

60. The Ceralumin series of aluminum alloys is derived from "Y" alloy, as will be evident from the ranges of composition shown below, the most important modifications being the deliberate addition and control of iron and silicon, which are each present in amounts up to 0.6 per cent as "impurities" in "Y" alloy, and the presence of a small amount of cerium. The cerium performs a three-fold function, in refining the macrostructure, in modifying the form of the iron-bearing constituent in the microstructure so as to minimize its embrittling effect, and in conferring improved "running" properties on the alloy.

61. Two compositions of Ceralumin are in current use for sand and die-castings. The first of these, Ceralumin "B," is used for intricate castings, the production of which calls for running properties out of the ordinary. The heat-treatment required is simple, involving only a single heating for 12 to 24 hours at 302 to 347 degrees Fahr. (150 to 175 degrees Cent.) terminated by quenching in water or oil, or merely air cooling. This simple heat-treatment and particularly the fact that it is not necessary to heat to high temperatures make the alloy suitable for large complicated castings which it is not desirable or convenient to quench from, say, 932 degrees Fahr. (500 degrees Cent.). The most notable feature of the mechanical properties attained by

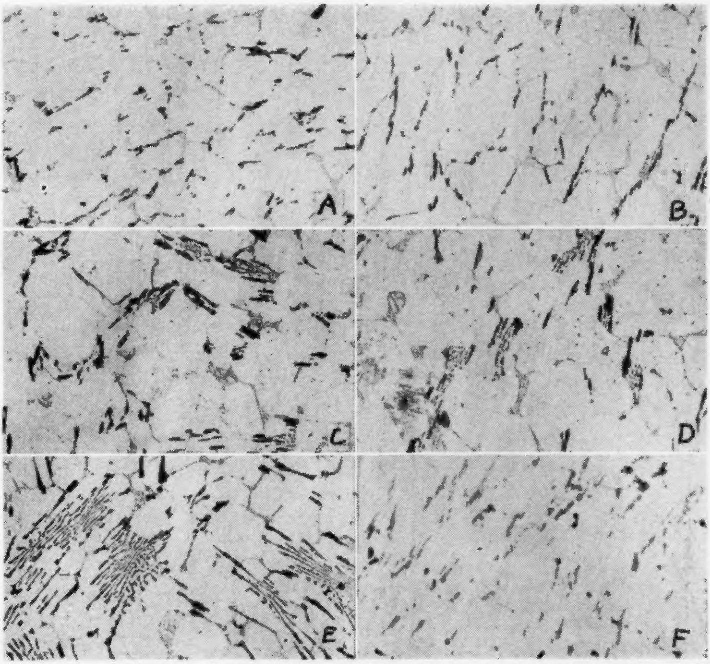

FIG. 10—MICROSTRUCTURE OF ALUMINUM ALLOYS x 150. (REDUCED ½ SIZE IN PRINTING.)

(A) "Y" ALLOY, SAND CAST, NOT HEAT-TREATED.
(B) "Y" ALLOY, SAND CAST, HEAT-TREATED.
(C) CERALUMIN "B," SAND CAST, NOT HEAT-TREATED.
(D) CERALUMIN "B," SAND CAST, HEAT-TREATED.
(E) CERALUMIN "A," SAND CAST, NOT HEAT-TREATED.
(F) CERALUMIN "C," SAND CAST, HEAT TREATED.

heat-treatment is the high proof stress, which confers a useful degree of rigidity without loss of ductility.

62. The composition of Ceralumin "B," which has a specific gravity of 2.75 is given in Table 6 as are the properties in 1 inch test bars, chill cast and sand cast.

63. Ceralumin "B" is used for the manufacture of such parts as water-cooled cylinder heads, impellers, gear-boxes, crank-cases, etc. Fig. 11 shows a large scavenge pump piston for the latest type of double-acting two-stroke marine diesel engine. Figs. 10C and D illustrate the microstructure of Ceralumin "B" before and after heat-treatment.

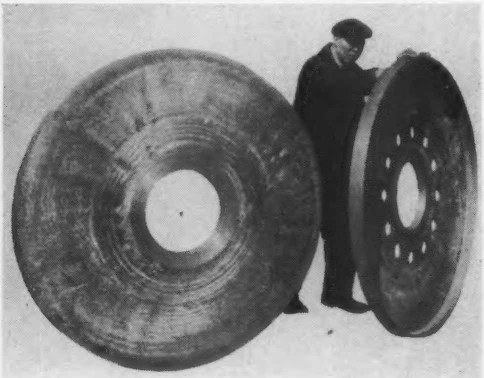

FIG. 11—PISTONS FOR SCAVENGE PUMP OF MARINE DIESEL ENGINE, ALUMINUM ALLOY, CERALUMIN "B."

Table 6

COMPOSITION OF CERALUMIN B, WITH PROPERTIES IN CHILL-CAST AND SAND CAST BARS.

Metal	Per cent	Metal	Per cent
Copper	1.0–1.75	Silicon	0.75–2.5
Nickel	1.0–1.75	Cerium	0.05–0.20
Magnesium	0.05–0.2	Aluminum	Remainder
Iron	0.3–1.0		

Properties in 1 in. Diameter, Chill-Cast Bar:

Maximum stress	29,120 to 33,600 lbs. per sq. in.
0.1% Proof stress	17,920 to 21,280
Elgonation on 2"	4 to 5 per cent.
Brinell Hardness	68 to 78

Properties in 1 in. Diameter, Sand-Cast Bar:

Maximum stress	23,520 to 22,880 lbs. per sq. in.
0.1% Proof stress	16,800 to 19,040 lbs. per sq. in.
Elongation on 2"	2 to 3 per cent.
Brinell hardness	65 to 75.

64. When higher strength and hardness are desired than are offered by Ceralumin "B," either Ceralumin "C" or Ceralumin "D" is used. These two latter are obtained from a single alloy (identified as Ceralumin "A") by different heat-treatments. The first stage in the heat-treatment of both is a "solution" treatment at 959 to 995 degrees Fahr. (515 to 535 degrees Cent.) for 6 to 20 hours, followed by quenching in oil or water. To produce the "C" form the castings are then tempered for 16 hours at 338 to 356 degrees Fahr. (170 to 180 degrees Cent.) and again quenched or air-cooled. The "D" form results, on the other hand, if the castings are allowed to age for 5 to 6 days at the ordinary temperature after the "solution" treatment.

65. The principal difference in composition between Ceralumin "C" (or "D") and Ceralumin "B" lies in the higher percentage of magnesium in the former, the composition of which is:

Copper	2.0 per cent.
Nickel 1.0	to 2.0 per cent.
Magnesium 0.5	to 1.0 per cent.
Iron 1.0	to 1.4 per cent.
Silicon 1.0	to 1.4 per cent.
Cerium 0.05	to 0.2 per cent.
Aluminum ....Remainder	

The higher magnesium content accounts for the different response to heat treatment, and the superior strength and hardness obtained. At the same time the higher proportion of magnesium in the alloy increases the shrinkage and makes it rather more prone to the formation of skins in sand molds. No difficulty from this cause is encountered with metal molds, and even in sand castings, and if reasonable care is taken to insure non-turbulent entry of the

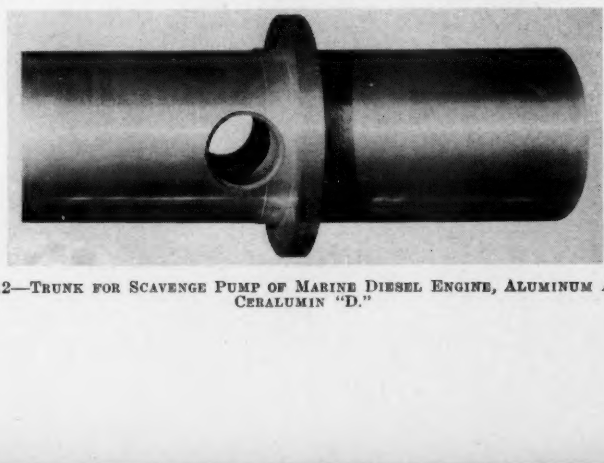

FIG. 12—TRUNK FOR SCAVENGE PUMP OF MARINE DIESEL ENGINE, ALUMINUM ALLOY CERALUMIN "D."

Table 7

PROPERTIES OF CERALUMIN "C" AT ELEVATED TEMPERATURES

Temperature Deg. C.	Maximum Stress, lbs. per sq. in.	Elongation on 2 inches. Per Cent
15	56,000	1.0
100	51,968	1.0
150	52,416	2.0
200	49,728	2.0
250	43,680	3.0
300	38,528	3.5
350	19,264	6.0

metal and to provide adequate risers, excellent results are obtained. An example of a large casting in Ceralumin "D" is shown in Fig. 12. This is the trunk to which the piston shown in Fig. 11 is attached. Typical die-castings in Ceralumin "C" and "D" are shown in Fig. 13.

66. The specific gravity of Ceralumin "C" is 2.79, and the mechanical properties in chill cast 1 in. diameter test-bars are:

Maximum stress—51,500 to 60,480 lbs. per sq. in.

0.1 per cent proof stress—47,000 to 53,800 lbs. per sq. in.

Elongation in 2 inches—1 per cent.

Brinell hardness—130-140.

Fatigue strength (20,000,000 reversals) — ±18,500 lbs. per sq. in.

The high fatigue strength is particularly notable. At higher temperatures the properties are as given in Table 7.

67. In sand cast bars the tensile strength required by Air Ministry specifications D.T.D. 255 is:

FIG. 13—DIE CASTINGS, ALUMINUM ALLOY, CERALUMIN "C" AND "D."

Maximum stress—Not less than 40,320 lbs. per sq. in., the 0.1 per cent proof stress being not less than 39,200 lbs. per sq. in., and the brinell hardness 130 to 140.

68. Ceralumin "C" is used particularly for die-castings such as pistons, where the maximum hardness and strength at ordinary and elevated temperatures are required. Figs. 10E and 10F show the change in microstructure from the "as cast" to the fully heat-treated condition of Ceralumin "C."

69. In many applications it is permissible to sacrifice some of the tensile strength and hardness of Ceralumin "C" in order to obtain a greater measure of ductility. An example where this

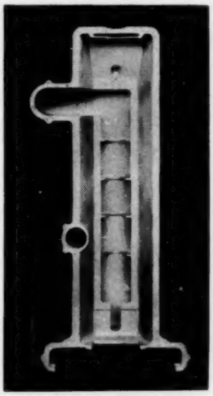

FIG. 14—CRANK CASE OF MAGNESIUM ALLOY. ELEKTRON "A.Z. 91."

consideration is important is found in air-cooled cylinder heads having deep, thin fins, which are liable to be chipped and broken if the ductility of the alloy is allowed to fall too low. Substitution of ageing for the tempering employed in Ceralumin "C" produces Ceralumin "D," having the properties; in a chill cast 1 in. diameter bar:

Maximum stress—42,560 to 47,040 lbs. per sq. in.
0.1 per cent proof stress—24,640 to 29,120 lbs. per sq. in.
Elongation in 2 inches—4 to 6 per cent
Brinell hardness—98-104

70. Air Ministry specification D.T.D. 250, governing Ceralumin "D" castings, requires a maximum stress of not less than 31,360 lbs. per sq. in. in a sand-cast test-bar, the 0.1 per cent proof

stress of which is not less than 25,760 lbs. per sq. in., elongation in 2 inches 1 to 3 per cent, and brinell hardness 98 to 104.

71. Fig. 13 shows a series of die-castings in Ceralumin "C" and Ceralumin "D."

72. From the data given above it may be seen that Ceralumin "C" has a higher strength and hardness than "Y" alloy in its normally heat-treated condition, while Ceralumin "D" with approximately the same tensile strength and hardness as "Y" alloy has the advantage of a higher elongation.

MAGNESIUM ALLOYS

73. In relation to their low specific gravity, which is in the order of 1.80 to 1.82, the alloys of magnesium could be described justifiably as of high strength, even in the normal cast condition without heat-treatment, since in this form tensile strengths of 20,160 to 26,880 lbs. per sq. in. in sand castings, and 22,400 to 33,600 lbs. per sq. in. in chill castings can be obtained without difficulty. On the strength of such properties as these Elektron castings find a steadily increasing range of application. The two casting alloys in most general use, which are known as Elektron "A. 8" and Elektron "A.Z. 91," have the approximate composition and properties as given in Table 8.

74. The diminishing solid solubility of aluminum in magnesium with fall in temperature would suggest that the magnesium-rich alloys containing aluminum should respond to a double heat-treatment in the same way as the light alloys of aluminum with copper, resulting in an increase of tensile strength, proof stress and hardness as compared with the "as cast" condition. This is what actually occurs in the alloy Elektron "A.Z. 91": a "solution" treatment at a temperature close to that of the eutectic produces a marked increase in the tensile strength and elongation, while the proof stress and hardness are not affected. When castings are tempered at 302 to 392 degrees Fahr. (150 to 200 degrees Cent.) following the solution treatment, the proof stress and hardness are raised to an extent depending on the precise time and temperature of the final treatment.

75. In Elektron "A. 8," with lower aluminum content, the response to the "solution" heat-treatment is similar to that of "A.Z. 91," but subsequent tempering has little effect on the proof stress and hardness. The range of mechanical properties obtained

by complete heat-treatment of the two alloys mentioned is approximately as shown in Table 8.

76. It will be seen that the tensile strength of these heat-treated magnesium alloys is comparable with that of the stronger aluminum alloys, such as "Y" alloy, although the specific gravity is 40 per cent less. This is a very remarkable achievement, which cannot fail to be of interest to the aircraft and other transport industries, and generally where stressed components, reciprocating at high speeds, are in use. The alloy containing 10 per cent of aluminum has a special claim to notice on account of the useful increase in proof stress which results from heat-treatment. This makes possible the use of Elektron in applications where it has not previously been suitable because of the relatively low proof stress in the normal cast condition. Heat-treated Elektron "A. 8" does not show a similar advantage, but on the other hand the high tensile strength and elongation suggest that it may be of

Table 8

COMPOSITION AND PROPERTIES OF ELEKTRON ALLOYS

	Elektron A. 8 Per cent	Elektron A.Z. 91 Per cent
Aluminum	8.0	10.0
Zinc	1.5	1.0
Manganese	0.3	0.3
Magnesium	Remainder	Remainder

Normal Cast Condition Mechanical Properties:

	Elektron A. 8		Elektron A.Z. 91	
	Chill cast	Sand cast	Chill cast	Sand cast
Maximum stress, lbs. per sq. in.	29,120–33,600	20,160–24,640	24,640–31,360	17,920–24,640
0.1% proof stress, lbs. per sq. in.	10,080–12,320	8,960–11,200	11,200–13,440	11,200–13,440
Elongation in 2 in. per cent.	6–10	3–5	4–8	2–4
Brinell hardness	50–60	45–55	65–70	60–65

Complete Heat-Treated Condition:

	Elektron A. 8		Elektron A.Z. 91	
	Chill cast	Sand cast	Chill cast	Sand cast
Maximum stress, lbs. per sq. in.	33,600–40,320	33,600–38,080	38,080–44,800	33,600–40,320
0.1% proof stress, lbs. per sq. in.	10,080–12,320	10,080–12,320	16,800–21,280	15,680–20,160
Elongation in 2 in., per cent.	12–17	10–15	3–5	2–4
Brinell hardness	50–60	50–60	70–80	70–80

special interest for parts in which stress concentration effects are liable to be encountered.

Applications of Elektron Castings.

77. The application of heat-treated Elektron castings is only in its infancy, but its further extension can be anticipated with confidence as it becomes realized in which directions the improved properties justify the additional expense of heat-treatment. Already the advantages of heat-treatment have been confirmed for such parts as crank-cases similar to that shown in Fig. 14, instrument brackets and large reciprocating air valves in marine engines.

High Strength Relation to Other Properties.

78. It has been mentioned in several places in the foregoing account how the term "high strength" may be related to various other properties, such as corrosion resistance, casting properties, and to economic considerations. It is probable, however, that the most important basis of comparison is found in the specific gravity of the various materials. The expression "specific tenacity" has been used to indicate the relations between engineering materials in this respect, and it may be interesting to classify from this

Table 9

	Tensile strength. lbs. per sq. in.	Specific gravity.	Specific tenacity.
COPPER-BASE ALLOYS			
Manganese bronze:			
Alpha-Beta (sand cast)	89,600	8.1	10,976
Beta (sand cast)	112,000	8.0	13,888
Aluminum bronze (sand cast)	100,800	7.5	13,440
NICKEL-BASE ALLOYS			
Monel Metal (sand cast)	67,200	8.8	7616
Silicon-Monel metal (sand cast)	89,600	8.8	10,080
ZINC-BASE ALLOYS			
Zinc-aluminum-copper-magnesium (chill cast)	44,800	6.7	6720
ALUMINUM-BASE ALLOYS (HEAT-TREATED)			
"Y" Alloy (chill cast)	44,800	2.8	15,904
Ceralumin "B" (chill cast)	33,600	2.75	12,320
Ceralumin "C" (chill cast)	56,000	2.8	19,936
Ceralumin "D" (chill cast)	44,800	2.8	15,904
MAGNESIUM-BASE ALLOYS (HEAT-TREATED)			
Elektron "A. 8" (chill cast)	35,840	1.8	19,936
Elektron "A.Z. 91" (chill cast)	40,320	1.8	22,400

aspect the nonferrous casting alloys which have been discussed. Expressing "specific tenacity" as

$$\frac{\textit{Tensile strength in lb. per square inch}}{\textit{Specific gravity}}$$

the various materials fall into the series shown in Table 9.

79. The alloys might be compared in a similar manner by tabulating the quotient of $\frac{\textit{Proof Stress}}{\textit{Specific Gravity}}$, and so on, but the list given is sufficient to indicate the information available for the designer working under certain limitations of weight. From this aspect the metallurgy of light metals has advanced to the point where the heat-treated alloys of aluminum and of magnesium can offer the means of actually increasing the strength of a casting of almost any other material, ferrous or nonferrous, while at the same time effecting a substantial economy in weight.

CHOICE OF MATERIAL

80. Other considerations, which have been mentioned previously, decide the choice of material for castings in favor of other nonferrous alloys. It has been the writer's endeavor to show in outline the fields in engineering practice for which each of the strong nonferrous casting alloys is best suited, and in which it has often gained and retained its position in the face of increasing competition from cast iron or steel, or from wrought ferrous and nonferrous material.

81. The indispensable requirement for extending the application of nonferrous casting alloys of high strength is increased confidence on the part of the engineer in the consistency and reliability of the castings produced. In nearly every case the full advantage of these special alloys is only gained at the expense of unremitting care, and often special technique, in the foundry; in these circumstances there can be no doubt as to the vital part which the foundryman plays in translating into consistently successful practice the results of research and development in physical metallurgy.

ACKNOWLEDGMENT

82. In collecting the data and illustrations for this paper the writer has drawn chiefly upon examples from the laboratory and foundries of J. Stone & Co. Ltd., Deptford, and his thanks are due to the directors of that company for permission to publish

the various particulars and photographs. Richardson, Westgarth, Ltd. kindly gave permission to reproduce in Figs. 11 and 12 photographs of large Ceralumin castings made for the latest R. W. double-acting two-stroke marine oil engine. The writer also acknowledges with pleasure assistance in the form of further information from J. McNeil of The Mond Nickel Company Ltd. (who supplied the photograph of Fig. 8), from National Alloys, Ltd. (by whom Fig. 9 was supplied), and from Fry's Metal Foundries Ltd. To his colleagues G. T. Callis, S. A. E. Wells, and J. P. Ellis, the writer's special thanks are due for much assistance in carrying out tests and preparing photographs.

DISCUSSION

In absence of the author, Mr. Murphy's paper was presented in abstract by Sam Tour, Lucius Pitkin, Inc., New York, N. Y.

DR. J. A. GANN[1] (*Submitted in Written Form*): Mr. Murphy's paper, particularly the section dealing with magnesium alloys, has been read with interest because it reflects the progress being made in England. We are especially interested in his statement that A8 and AZ91 are the two magnesium casting alloys in most general use. Information at our command, including published literature and direct oral reports, has indicated that AZG (6 per cent aluminum, 0.2 per cent manganese, 3.0 per cent zinc) has been the most widely used sand casting alloy, while VI (10 per cent aluminum, 0.2 per cent manganese) has been used for die castings. What is the explanation for this change in alloy? Is it based on economic or technical considerations?

We are likewise interested in the progress reported in heat treatment. The very marked property improvements thereby obtained have been largely responsible for numerous commercial applications of magnesium alloys in the United States. The heat treatment of certain types of magnesium castings has been standard practice with us for more than 5 years, while heat treated castings were used experimentally as early as 1919.

It should not be inferred from the statement "The alloy containing 10 per cent of aluminum has a special claim to notice on account of the useful increase in proof stress which results from heat treatment" that alloy AZ91 is the only composition whose proof stress is increased by heat treatment. Actually, such property improvement is a common phenomenon and occurs in the binary as well as in the polynary magnesium alloys containing the metals,—aluminum, manganese, tin, and zinc in excess of their room temperature solid solubilities.

In the "as-cast" state, the addition of zinc to a given magnesium-aluminum-manganese alloy produces approximately the same change in

[1] Chief Metallurgist, Dow Chemical Co., Midland, Mich.

properties as the addition of two-thirds as much aluminum. In the heat treated condition, however, the magnesium-aluminum-manganese-zinc alloys possess better properties than would be normally expected on the basis of a strictly additive effect. This holds true even in aged alloys like A8 and AZ91 which contain less zinc than the room temperature solid solubility of zinc in the binary system. No investigations have been made to determine how the zinc functions in such alloys. It may lower the solid solubility of aluminum in the magnesium, or the aluminum may lower the solid solubility of zinc in magnesium, or both effects may occur.

In our paper* we stated that the magnesium-aluminum-manganese-zinc casting alloy used in this country, has a nominal composition of 6 per cent aluminum, 0.2 per cent manganese, 3 per cent zinc. It possesses a distinct advantage over the A8 and AZ91 alloys in that this one alloy, with its various heat treatments, yields substantially the same sets of properties that are obtained from the other two alloys. Table 10 shows this comparison using the averages of the data given in Table 8 of Mr. Murphy's paper. Although the Dowmetal has, in general, a somewhat higher strength and ductility than the Elektron, and the latter has a somewhat higher proof stress and hardness than the Dowmetal, most of these differences in properties are no greater than the normal variations from heat to heat of one and the same alloy composition.

Our final question relates to the heat treatment given alloy A8 in order to obtain the properties given in Table 8. The term "complete heat treatment" has been used as a common expression applying to both alloys. It distinctly refers to a solution heat treatment plus aging (tempering) in the case of AZ91, but we believe it refers only to a solution heat treatment in the case of Alloy A8. The high percentage elongation of A8 substantiates this view, since aging of this alloy lowers the percentage elongation even though it has very little effect on the proof stress and hardness.

Table 10

AVERAGE PROPERTIES OF SAND CAST MAGNESIUM ALLOYS

Alloy	Condition	Maximum Stress, lb. per sq. in.	0.1 Per Cent Proof Stress, lb. per sq. in.	Elongation in 2 in., %	Brinell Hardness
Elektron A8	As Cast	22,000	10,000	4	50
Elektron AZ91	" "	21,000	12,000	3	62
Dowmental H	" "	27,000	10,000	6	49
Elektron A8	Heat Treated	36,000	11,000	12	55
Dowmetal H	Heat Treatment 1a	36,000	20,000	11	52
Elektron AZ91	Heat Treated	37,000	18,000	3	75
Dowmetal H	Heat Treatment 3a	40,000	17,000	5	69

* GANN, DR. J. A., and BROOKS, M. E., "Founding of Magnesium Alloys." TRANS. A.F.A., vol. 43, p. 583 (1935), also June 1936, vol. 7, No. 3, p. 585.

SAM TOUR[2]: I wish to compliment Mr. Murphy on his very able paper. I find one or two items I would like to comment on at the bottom.

Terminology varies somewhat between England and the United States in the use of the term "die casting." Mr .Murphy uses the term "die casting" in reference to the casting of aluminum bronze. In England, they call all casting in dies "die casting," whereas, in the United States we usually consider the term "die casting," as referring to "pressure die casting" and simply hand-pouring into molds is called "permanent molding." His use of the term "die casting" with reference to aluminum bronze should, I believe, be considered to refer to what we call permanent molding, whereas, when he speaks of zinc alloy castings, then he really refers to pressure die casting.

In discussing the zinc base alloys Mr. Murphy states that the presence of 0.1 per cent magnesium is found to improve resistance. In this country we have found quite definitely that only 0.03 to 0.05 per cent magnesium is necessary for this and more tends to increase the difficulties in the casting. The usual practice in this country therefore is to use not more than 0.05 per cent magnesium. With reference to the same zinc base alloy, Mr. Murphy states the tin and lead must not exceed 0.01 per cent. The practice in this country is that the tin must not exceed 0.005 per cent and the lead must not exceed 0.007 per cent. In other words, we hold the maximum impurity content at considerably lower amounts than they do in Europe.

O. W. ELLIS[3]: In the section on manganese bronze, Dr. Murphy makes the following statement: "The tin content does not change much from 1 per cent." I think in our practice in this country the attempt has been made to reduce the tin content to the smallest amount possible, not to retain it at what seems to me a rather high percentage.

MR. MURPHY (*Reply to Discussion Submitted in Written Form*): I am much obliged to Mr. Wick for his kind remarks from the Chair. It was a matter of keen regret to me that I was unable to attend the conference, and I must express my special thanks to Mr. Tour for presenting my paper.

As Mr. Tour pointed out, Fig. 5A should be described as "All Alpha"; the specimen involved was correctly described in Table 4, and the figure title has now been corrected. The difference between American and British practice in the interpretation of the term "die casting" is unfortunate, and Mr. Tour's explanation is correct. In England, die-casting is only taken to mean casting in a die; when closer definition is required the word "gravity" or "pressure" is prefixed.

My reference to zinc-base alloys was of the briefest, as it was only included to illustrate a general thesis, and the remarks on magnesium, tin and lead contents were intended to indicate limits; they should not be understood as representing average values necessarily typical of British or European practice. Nevertheless, Mr. Tour's comments are of considerable interest.

Mr. Ellis' observation gives me the opportunity to say that tin-free

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[2] Vice President, Lucius Pitkin, Inc., New York, N. Y.
[3] Director Ontario Research Foundation, Toronto, Can

manganese bronzes are quite common in England. Perhaps I ought to have said *when tin is present* it does not vary much from an amount of 1 per cent. The view is held by some that a tin content of this order is desirable because it has a favorable effect on corrosion resistance, especially in seawater.

Dr. Gann raises a number of interesting points regarding magnesium alloys. It is rather remarkable that while the tendency in England is for the 8 per cent aluminum alloy to replace the 6 per cent aluminum, 3 per cent zinc alloy, Dr. Gann's company is moving in the opposite direction. The fact appears to be that on general merits there is not a great deal to choose between the two compositions, but on the whole we prefer A8 because we find it has superior dynamic properties (e.g. fatigue strength) and strength at elevated temperatures. Economic considerations are not involved in this choice.

I cannot accept the implication of Dr. Gann's comments on Elektron AZ91 and its response to heat-treatment. It might be thought from his remarks that comparable improvement in proof stress would result from tempering any magnesium alloy which had previously undergone solution treatment and which contained a second element, e.g. aluminum, in amount exceeding the limit of solid solubility in equilibrium at room temperature. This would be expected from analogy with aluminum-base and many other alloys, but the behavior of magnesium alloys is somewhat unusual in this respect. As an example, 8 per cent of aluminum is considerably in excess of the limit of solid solubility at the ordinary temperature, but tempering the solution treated alloy does not produce a useful increase in the 0.1 per cent proof stress.

I have not had experience of so high a proof stress in the heat-treated 6 per cent aluminum, 3 per cent zinc alloy as the 17,000 lb. per square inch reported by Dr. Gann, but I presume that he has sufficient evidence to be satisfied that this is a typical figure.

Referring to Table 1 in Dr. Gann's contribution, it ought to be mentioned that the data taken from my paper were obtained on bars of 1 in. diameter cast in the vertical sand molds which are now standardized by the British Air Ministry and the British Standards Institution. The test-pieces machined from these were of 0.564 in. diameter with a gauge length of 2 in. I believe Dr. Gann's values are taken from bars cast approximately to shape, having a diameter as cast of approximately 0.6 in. If this is the case, the two sets of data are not strictly comparable, as casting a shaped test-bar gives a distinct improvement both in tensile strength and elongation.

In reply to Dr. Gann's final question, the term "complete heat-treatment" was intended to indicate solution treatment alone in the case of A8 alloy, and solution treatment followed by tempering for AZ91.

Slags and Gases in Cupola Operation

By A. H. Dierker*, Columbus, Ohio

Abstract

The theory of combustion in cupola operation is first discussed. Belden's work on cupola gases and temperature is reviewed. Oxidizing and reducing conditions and the factors affecting these conditions are discussed in detail. A study of cupola slags is presented as is the question of chemical reactions taking place in the operation of the cupola as a melting unit.

Introduction

1. In attempting to secure better and more uniform metal at lower costs, the gray iron foundryman has, in recent years, given considerable thought to his cupola. Attention in particular has been directed toward improving his practice by a more efficient utilization of materials available for the metal charge, by proper control of blast volume, and by securing the proper superheat to his metal. That effort along these lines is worthwhile, has been demonstrated, we believe, by the generally improved quality of iron in castings made by those foundries who have given these items proper attention.

2. There are several important factors, however, which are usually overlooked in studying cupola operations. Chief among these is the nature and effect of gases and slags generated in the cupola when in operation. We feel these items to be of sufficient importance to warrant some discussion at this time.

3. We are assuming that all those interested in the subject matter of this somewhat brief discussion are familiar with the construction and operation of the standard foundry cupola, and hence we believe it unnecessary to include any elementary description in this paper.

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* Research Engineer, Engineering Experiment Station, Ohio State University.

Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

Theory of Combustion

4. According to the accepted theory of combusion, air entering the cupola through the tuyeres combines with the carbon in the coke to form CO_2 (carbon dioxide) gas. In the presence of excess incandescent carbon this CO_2 almost immediately combines with this excess carbon to form CO (carbon monoxide). This CO passes up through the charge until it meets the free oxygen in the air coming through the charging door when it burns to CO_2 forming the familiar blue flame seen above the charge while the cupola is in operation.

5. Obviously these reactions do not go to completion nor do they all take place just at the tuyere opening, for some of the air will have penetrated well toward the center of the cupola before all the oxygen has been used up. Furthermore, we would not expect the reactions to be completed at the tuyere level, for the air and gases start up as they are formed or enter through the tuyeres. Hence we find that most of the reactions take place a short distance above the tuyere level.

6. Belden[1], in a very complete study of cupola gases and temperatures, determined the upper limit of free oxygen. He also determined the zone of maximum temperatures. The outer edge of both these zones coincides with the area where severe cutting action of the refractories takes place. Unfortunately this area is not unfamiliar to the average foundryman.

7. In Fig. 1 is shown the upper limit of free oxygen and the line of maximum temperature as determined by Belden who felt that, for best results, melting should take place above this line. Under these conditions the metal would be heated and melted in a reducing atmosphere; i. e., free from free oxygen and high in CO content, and then pass quickly as a liquid through the oxidizing zone into the crucible.

Oxidizing and Reducing Conditions

8. At any rate, it is obviously true that both oxidizing and reducing conditions occur simultaneously in the cupola and a little study of Fig. 1 will further reveal that not all the metal charge will be subjected to be same conditions. That part of the charge near the cupola lining will evidently be subjected to

[1] Belden, A. W., *Foundry Cupola Gases and Temperatures*, U. S. Bureau of Mines, Bulletin 54.

severe oxidizing conditions, while that part near the center may meet little, if any, free oxygen. Since the line of maximum temperature is far from straight it would appear evident that all the metal, even if uniformly sized, would not melt at the same level.

9. Experienced cupola operators know that the location of the regions just described will be changed with any change in cupola operations such as height of coke bed, size of coke and metal charges, blast volume, and condition of lining. Any change in the location of these zones will be reflected in a change in the properties of the metal at the cupola spout.

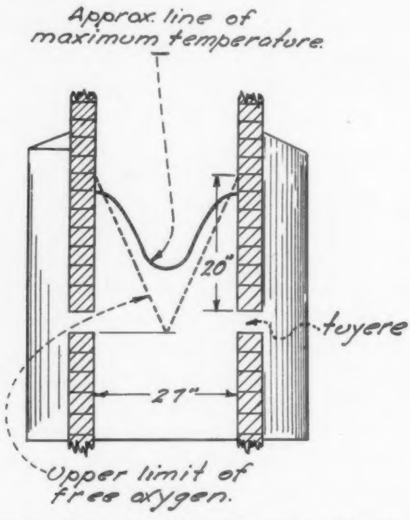

FIG. 1—BELDEN'S UPPER LIMIT OF FREE OXYGEN AND LINE OF MAXIMUM TEMPERATURES.

10. Although a certain amount of oxidation is bound to take place, there is no reason for assuming that this is particularly harmful if subsequent conditions to which the metal is subjected tend to remove the oxides. Excess oxidation in the absence of corrective treatment is undoubtedly harmful. In Table 1 are given the results of tests of high strength electric furnace iron to which, iron oxide in the form of mill scale, was added in the ladle. Although the effect on tensile strength was slight, there is a noticeable decrease in transverse strength and deflections.

11. Gas compositions should not be discussed without consideration of temperatures for the rates of the reactions discussed depend to a large degree on the temperature of the gases involved. With temperatures above normal in a cupola the metal is "superheated" with quite apparent changes in its physical properties. It is not easy to prove or disprove any of the many theories advanced for the apparent phenomenon of superheated metal for the reason that it is difficult, indeed, to superheat cast iron without changing its composition.

12. As has been previously pointed out by the author[2]; at elevated temperatures carbon becomes an active deoxidizer and we would expect, in the presence of free oxygen or reducible

Table 1

EFFECT OF LADLE ADDITIONS OF IRON OXIDE ON COMPOSITION AND PHYSICAL PROPERTIES HIGH STRENGTH IRONS

Melt No.	Ladle Additions	Analyses—Per Cent TC	Si	Mn	P	S	Trans. Strength[1] Break lbs.	Def. in.	Brinell No.[2]	Tensile Strength[3] lbs. per sq. in.
80-1	None	2.69	2.38	.49	.03	.038	4640	.211	241	56,820
	0.8% Mill Scale	2.73	2.30	.46			3550	.135	241	50,550
80-4	None	2.76	2.42	.47	.03	.036	4710	.235	235	54,480
	1.6% Mill Scale	2.76	2.25	.46			4360	.214	235	53,100

[1] 1.2 in. Round bar tested on 15 in. centers.
[2] At center of transverse bar.
[3] 0.8 in. bar machined from broken half of transverse bar.

oxides, reactions to take place that would, if nothing else, tend to lower the carbon content. Our experience with a large number of melts of cast iron made in an acid lined electric furnace is that the general tendency of superheating the metal has been to reduce the carbon and increase the silicon content. This is to be expected, for at high temperatures silicon is readily reduced by carbon from its oxide or from silicates.

13. In the absence of any slag we would expect oxidation of the carbon at the metal surface. Saeger and Ash, in an investigation[3] of the effect of superheat on gray cast iron of several different compositions, melted and superheated the metal

[2] *Silicon and Manganese as Deoxidizers in Cast Iron,* Trans. A.F.A., Vol. V, No. 1, Feb., 1934.

[3] Saeger, C. M., Jr., and E. J. Ash, *Properties of Gray Cast Iron as Affected by Casting Conditions,* Trans. A.F.A., Vol. V, No. 1, Feb., 1934.

in an induction furnace with a crucible of commercial magnesia. There were no reducible oxides present but nevertheless, as pointed out by MacKenzie in the discussion of this paper, the analysis of the various test bars shows a noticeable drop in carbon with increasing superheat.

14. As stated previously in this discussion, reducing and oxidizing conditions exist simultaneously in the cupola so it is entirely possible for silicon to be both reduced and oxidized at the same time, and while carbon is being absorbed in one place it is being oxidized in another. The silicon drop from charge to final melt does not necessarily represent the total amount oxidized, but may better be considered the difference between the silicon oxidized and that reduced. Under certain conditions it is easily possible for the silicon reduced to exceed that oxidized, in which case there would be an actual silicon pick-up between charge and melt. This happens at not infrequent intervals in commercial operations.

15. Another factor that may or may not prove on investigation to be important is that silicon is not only volatile at high temperatures, but it can form volatile silicon sulphides. Some foundrymen have contended that high silicon irons are less prone to pick up sulphur than the low silicon variety. It is easy to suspect that silicon may be an important factor in the well known fact that low silicon steels, in passing through the cupola, will pick up more sulphur from the gases than cast iron scrap or pig iron.

CUPOLA SLAGS

16. In the normal operation of a cupola considerable refuse material will reach the melting zone. This material consists of the ash in the coke, sand and rust adhering to the scrap and pig iron, perhaps some oxidized iron, manganese and silicon and part of the refractory lining. These materials fuse in the melting zone and form a viscous, sticky mass, which, unless gotten rid of, may seriously interfere with the cupola operation or perhaps stop it altogether.

17. The usual method for handling this slag is to add some fluxing material which thins the mass to a point where it can be removed through a hole in the side of the cupola provided for that purpose. The object of practically all foundrymen is to remove the slag as quickly, effectively, and cheaply as possible.

18. Several years ago the author[4] pointed out that not only a more fluid slag could be secured by substituting dolomite for limestone as a cupola flux, but that the nature of the slag had an effect on the metal composition. Later investigations have indicated that the type of slag formed has a noticeable effect on the physical properties of the metal as well.

19. In a commercial foundry making light section castings where machinability is important, a series of slag samples were taken at regular intervals during one run of the cupola. Analysis of these slags showed considerable variation, with an increase in silica toward the end of the run. Following are the analyses of the first and last samples:

	First of Heat (per cent)	Last of Heat (per cent)
Silica	40.9	56.0
Alumina	22.4	21.3
Iron oxide*	1.5	0.9
Lime	24.4	15.4
Magnesia	8.6	5.5

* Calculated to FeO.

20. Although there was little change in metal composition the castings from the first of the melt were normal, while those from the last of the melt showed hard spots and gave difficulty in machining.

21. The slags of lowest melting point are not always the best working slags, for viscosity must be considered. A slag of one composition could easily be more viscous than a slag of somewhat different composition and with a melting point a hundred or more degrees higher. Herty[5] and associates, in investigating a portion of the lime-silica system found the lowest viscosity, not at the low melting eutectic of 37 per cent lime, but at 48.2 per cent lime ($CaOSiO_2$) which composition melts at a temperature more than 100 degrees higher.

22. A free flowing liquid slag is not necessarily harder on the refractories than a viscous one; in fact, quite the contrary could easily be the case. Certainly proper slagging of a cupola is an important part of its operation.

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[4] *The Use of Dolomite as a Flux in Cupolas*, Ohio State University, Engineering Experiment Station News, Vol. IV, No. 3, Oct., 1932.

[5] Herty, Hartgen, Frear, Royer, Temperature-Viscosity Measurments. U. S. Bureau of Mines, R. I. 3232, June, 1934.

CONCLUSION

23. Although the mechanical details of the construction and operation of a cupola are quite simple the physical chemistry involved in its use is not. It is unfortunate that a thorough study of the reactions taking place in the operation of this efficient melting unit has not been made. Certainly such a study would prove profitable, indeed, to the gray iron foundryman.

DISCUSSION

In absence of the author this paper was presented by Dr. C. H. Lorig, Battelle Memorial Institute, Columbus, O.

H. R. CLARKE:[1] Is there a difference in the physical properties after the cupola has run 45 minutes with 2 per cent limestone, and a cupola under the same conditions after 45 minutes with 4.5 per cent limestone, the limestone being 4.5 per cent of the iron? Making all other conditions the same, what happens to the physical properties of iron if you increase the percentage of limestone?

F. J. WALLS:[2] I do not think there would be much change but if I was going to increase the percentage of limestone, I would also increase the percentage of sand going into the cupola and make a voluminous slag, something that has not been brought out in this paper. I think there is probably a real necessity for controlling volume of slag, as well as composition, in order to control the physical properties of your iron.

I think Mr. Clarke's own work has shown that by leaving all other conditions the same in the cupola and increasing the limestone above the normal amount to take care of a good fluid slag that he has lowered the physical properties by about 10 or 15 per cent. But I do believe however if he had increased the volume of slag by introducing the materials to react with the limestone, he would have increased his properties by 20 per cent, which I have proved. What do you think of that, Mr. Clarke?

MR. CLARKE: No, I tried that, too. If you increase your volume by simply increasing your limestone you will get no beneficial results.

MR. WALLS: I did not say simply increasing the limestone; I said by properly balancing the slag by introducing materials to react with the increased limestone and thus increasing volume.

MR. CLARKE: Maybe I am not that far along but I have noticed a very decided difference in the physical properties with a basic slag and with an acid slag.

MR. WALLS: I really believe that we are coming to the point where we are going to control the by-products of the cupola the same as the steel men have done. Apparently, something has been lost sight of in the two by-products, the gases and the slags. If we control those, we

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[1] Resident Mgr., Sloss-Sheffield Steel and Iron Co., Chicago.
[2] International Nickel Co., New York, N. Y.

are certainly going to have a better product. I believe grain size and physical properties, are going to be controlled by controlling slags.

H. DEANE:[3] I do not believe any of us know very much about slags in the cast iron field and I believe some provision should be made where more study is given as to what effect slag has on the iron and how are we going to judge whether a slag coming through a cupola is a good or a bad slag. Are we going to judge by composition, or color, or how are we going to judge it? I have talked with a number of men about slag and they say, "Well, that is pretty good." But to get right down to concrete facts, you can not find out just exactly how slag composition should be balanced, how much of this, how much of that, or what color, etc.

DR. J. T. MAC KENZIE:[4] I think we know less about slags than anything in the cupola.

W. H. SPENCER:[5] I do not know whether we know less about slags than anything else in the cupola or not. But we know less about them than anything else that we know we do not know about. We know slags affect our iron but we do not know exactly how or why. I would like to hear from some one who has been making microscopic examinations of slag.

MR. CLARKE: While I have not done a great deal of very definite work as yet, I think that the deciding factor in slag is its volume and blackness, unless one wants to go further and secure an analysis of it. Putting it rather crudely, the higher the iron oxide in slag runs and the higher the manganese runs, the blacker it will be. My observation has been that the best slag is the blackest slag and slag of the largest volume. Double the volume of your slag and increase the percentage of manganese oxide and iron oxide in it, if all conditions are kept the same, you most likely more than double the amount of oxides you have removed from the iron.

As to the composition of slags, I have done some work with slags in small crucibles. I have worked with basic slags made up of sand, lime and soda ash and with acid slags made up of the same materials differently proportioned. I found that if a piece of red hot iron wire is immersed in fluid basic slag, the oxide tarnish is not removed. If, however, the same red hot wire is immersed in an acid slag all oxides are removed and the wire looks as if it had been dipped in strong hydrochloric acid. The acid slag I used in this experiment showed about 70 per cent silica, 15 per cent lime and 15 per cent sodium oxide. This test would naturally make one favor acid slags as an agent for removing oxides from iron.

In one foundry during a heat of 1¼ hours, we observed that with a normal operation using about 2½ per cent limestone, the first iron out of the cupola showed a very open grain and after about 15 minutes the grain began to close. After 30 minutes, we obtained a very close

[3] Deere & Co., Moline, Ill.
[4] American Cast Iron Pipe Co., Birmingham, Ala.
[5] Sealed Power Corp., Muskegon, Mich.

grain. I observed in several foundries, that the first iron shows the most open grain.

There are two explanations. One is a higher carbon, but that will not hold water because sometimes we find the first iron to be of lower carbon than some of the iron farther on in the heat. The logical explanation is that during the first part of the heat there is practically no slag and as the slag begins to get worked up and gets into contact with the iron, it removes the oxides and closes the grain.

Our next step was to deliberately put into the coke bed, mostly below the tuyeres, two 9-cubic foot wheelbarrows of sand and about half as much limestone as there was sand and about half as much sodium carbonate as limestone. We put a big charge of this flux mixture about one foot above the sand bottom, then mixed the flux with the coke until the tuyere level was reached. With this flux added in this way, we could just about depend in getting an acid slag with our first iron. All the iron from this heat showed a very close grain.

The next step was to increase the limestone and put it in the bed. We doubled the amount, using around 4 or 5 per cent and used no sand. The grain of the iron was open from the very beginning to the end of the heat. In fact, the most open grained iron was near the very end of the heat. The strength was decreased about 10 per cent, so that we actually did control the grain of the iron by watching the composition of the slag. The more basic you get the slag the more open grained will be your iron and the weaker. The more acid you get it, the closer the grain will be.

It is logical that a large volume is more effected than a small volume. But the important thing, in my opinion, is the composition.

DR. MACKENZIE: I would like to ask Mr. Clarke how he explains extra strength of electric furnace iron run under a calcium carbide slag with no silica at all?

MR. CLARKE: Strong basic slags containing calcium carbide have been used to refine steel. Calcium carbide is most likely just a strong reducing agent similar to calcium silicide. The action of an acid slag is different because there is no separation of oxygen and metal—both are simply absorbed by the slag. I do not think one would get much benefit from a basic slag until temperatures are higher than those reached in a cupola.

MEMBER: To affect a betterment in the quality of the iron, is it necessary to use more limestone in high steel mixes than in the ordinary straight mix?

MR. CLARKE: No, with a high steel mixture you would be more likely to get more oxidation in your cupola. What you need is a large volume of acid slag. If you simply add limestone, you will make your slag more basic and it will be less capable of absorbing oxides. Of course when you increase limestone you necessarily increase your slag volume, but I am sure that you would not be benefited.

J. GRENNAN:[6] The question of grain size is confused somewhat by

[6] University of Michigan, Ann Arbor, Mich.

two grain sizes that were mentioned in the discussions of the paper by Dr. DiGiulio and Dr. White previously. In discussing this paper, Mr. MacPherran discussed the austenitic grain size. Austenitic grain size, I think, is the important feasure in regard to these slag ideas. In the electric furnace, we get considerable control through the addition of oxides. Large austenitic grain structure increases the strength. Dr. Murphy, of the University of Michigan, I think, has proved that quite conclusively. Dr. DiGiulio showed some effects of the austenitic structure in his paper.

Now as to the question of basic and acid or lime and silica slags, the basic slags are more reducing than the acid or silica slags. The silica slags will give you the larger austenitic grain structure. This larger austenitic grain structure also seems to be a feature in the heat treatment of cast irons, particularly in regard to cylinder liners. So that there is quite a field for study here.

Now in the grain size studies that Dr. Murphy is making, he gets his control by the addition of oxides. A very small amount of steel added to an electric furnace heat will have the effect of giving this more acid condition. That is, the oxides carried on a small piece of steel have a very marked effect, so that in the future I think there will be considerably more discussion and I would like to see Dr. Murphy have a paper on this subject at the next meeting of the A.F.A.

MR. SPENCER: In paragraph 14, in discussing cupola changes, Mr. Dierker says, "Under certain conditions it is easily possible for the silicon reduced to exceed that oxidized, in which case there would be an actual silicon pick-up between charge and melt." I would like to know the conditions under which silicon pick-up in the cupola may be obtained.

A. H. DIERKER (*Reply to Discussion Submitted in Writing*): I was glad Mr. Deane mentioned the need of further study of cupola slags. Such a study should prove just as profitable to the gray iron producer as it has to the steel manufacturer.

The author agrees with Mr. Clarke that a higher iron oxide content will make a blacker slag, but he cannot agree that such a slag is necessarily a good slag. In fact, we would expect quite the contrary to be true for we know, from equilibrium studies of slags and metals in contact, that the oxides in the metal tend to reach an equilibrium with those in the slag and in general, the higher the oxide content of the slag the higher will be the oxide content of the metal.

In the experiments testing the deoxiding power of acid and basic slags described by Mr. Clark, it would appear, from the data furnished, that both slags tested might well be classed as basic. The terms basic and acid when used in connection with slags have quite definite meanings and it would be unfortunate if the subject were confused by the indiscriminate use of these words. The change in physical properties of an iron from the first iron out of the cupola to that tapped 20 or 30 minutes later is not necessarily due to the formation of any slag. The cupola by this time is undoubtedly operating at a higher temperature and it is also easily possible for the height of the coke bed to have changed considerably, both of which factors would have affected the

properties of the iron melted. The author cannot agree that removing the oxides from iron will "close the grain" and increase the strength. Investigational work already done on this subject would indicate quite the contrary to be the fact. We would suspect the change noted in the iron to be due to some other cause.

Answering Mr. Spencer's question regarding silicon pick-up. My statement in paragraph 14 regarding the possibility of silicon pick-up from charge to melt was based on tests of a cupola operating in regular production in a commercial foundry. The charge was sampled, and controlled carefully enough to prove, beyond reasonable doubt, that there was, under the conditions existing, an actual pick-up of 0.11 per cent of silicon from charge to melt. I might also mention that keeping all other conditions the same and merely changing the slag composition caused a loss in silicon instead of a pick-up.

Mechanical Sand Handling For Low-Tonnage Foundries

By E. W. Beach,* Muskegon, Mich.

Abstract

The author outlines the condition of the sand that may be expected where mechanical sand conditioning equipment is not used. He then defines the "perfect" sand and explains the functions of the various parts of a system designed for a small jobbing foundry together with the advantages. Savings produced by the installation of such equipment in one shop together with maintenance costs are cited.

1. The fact that properly prepared sand is a fundamental requirement in the production of uniform castings of high quality, need not be discussed. Uniformly prepared sand may be obtained at a comparatively low initial investment charge for equipment, and the savings effected in materials and labor by means of such installations may be measured in dollars rather than in cents. These savings, effected by the use of mechanical sand handling, may be made not only in the plant producing a standard specialty which duplicates in the thousands, but also in the foundry producing work of a miscellaneous character—the so-called "jobbing shop."

2. The hand process of sand preparation will not be described in detail except to review the cumbersome and laborious items;—molds shaken out at the end of the day—castings removed—the bucket or hose for a wet down—the night men with the shovel—and a sand heap by the bench or in a windrow on the side floor in the morning from which no attempt has been made to remove tramp material. It is into this heap the molder hopefully thrusts his hand in the morning and then reaches for his shovel.

3. Let us enter the average foundry in any sizeable city and go with Jerry Duncan to his floor. His heap is in one of two conditions:

(*Usually*) The sand is tossed back adjacent to his bench in almost the same condition as it was after the wet down of the night before,—untempered by the moisture added; a mix-

* Engineering Executive, Campbell Wyant & Cannon Foundry Co.
Note: This paper was presented at a session on Materials Handling and Foundry Equipment held at the 1935 Convention of A.F.A. in Toronto, Canada.

ture of wet soggy lumps and dry cakes ready for a double cutting over by hand that will not only spoil Jerry's disposition but will take out of him two of his peppiest hours, even if he only spends 15 or 20 minutes at the task.

(*Possibly*) A heap that is in fairly good condition, but it is not uniformly tempered as to moisture or permeability, even though it has had the beneficial help given by the use of any one of the portable riddles, revivifiers or aereators that have been developed during the past 10 years. Excellent as these equipments are, they cannot perform miracles. They take the sand fed into them as it comes, clean it thoroughly of tramp material and aereate it to a degree, but unless it has been uniformly turned over several times, before passing through the disintegrating mechanism, it will still lack uniformity in the two essentials of perfectly conditioned sand—moisture and permeability.

BOND

4. Many probably will raise the question, "What about the third essential, bond?" If, in the instance of the first heap, a standard bond test were made, it would doubtless show a strength natural to or a little greater than the raw sand, due, no doubt, to the moisture added and the generous spanking with the shovel given it by Jerry in his 20 minutes of setting-up exercises before beginning his real day's work.

5. In the second heap, if new sand or a prepared bonding material has been added to the heap by careful and uniform distribution before passing it to the disintegrator, the strength indicated by a standard test will doubtless be somewhat higher. In each case, especially the latter, to acquire this rather doubtful but desirable condition, there has been a needless and costly waste of bonding material. It matters not whether this waste of bond has been through the addition of new sand or a prepared binder, since the actual intrinsic worth of the bonding material used is far greater than is required in the third heap which has been mechanically handled from floor to mold and with all of the manual operations dispensed with, except that of cleaning up the floor at night.

PERFECT SAND

6. This third heap (called "heap," although it is in a hopper) is a result obtained from *a combination of exact measure-*

ment of materials, energy and time. After decrying the old order of methods and the resulting conditions, nothing short of perfection in the quality and texture of sand which is obtained from mechanical manipulation may be expected. Taking the word "perfection" as the target, what is it the foundryman expects? He expects perfection in sand uniformity, predetermined by a standard obtained by experiment and fixed by the requirements of the castings to be produced in it. Such uniformity as this, can only be obtained by mechanical methods and the exact measurement of time and materials.

7. The following represents the operation of a very simple plant which will give the desired results—perfectly prepared sand —at a minimum of investment, a low labor cost, and an actual saving in materials.[1] The cycle of operation begins at the same point from which the floor sand heap was reviewed—the end of the day.

One Manual Task

8. The castings are removed from the sand when the molds are dumped, and the sand is shoveled into carriers in a central gangway at floor level. This is the only arduous manual labor performed in the entire operation up to the point when the sand again reaches the mold dumping stage on the following day.

9. In the case of the snap flask floor, molds and castings are dumped into carriers and the castings hooked out in the same manner as if they had been dumped on the floor itself. The carrier is a low tray suspended from a monorail. Sides of the tray are of a height easy to shovel into because the position of the next operation requires that the tray be lifted by the chain hoist only sufficiently for it to clear the floor by perhaps 6 in.

Conditioning.

10. The sand in the tray is conveyed to the regenerating plant and slides into place over a hopper, the latch, with which the hopper is equipped, is kicked out, the bottom opens and the sand cascades onto a vibrating screen which removes all the tramp material. (Fig. 1.) This in turn is passed over a magnetic separator to extract the iron from the refuse. A short belt conveyor under the screen carries the sand to an elevator which conveys

[1] Amos, Max A. and Grace, R. W., *"Handling and Conditioning of Sand in a Small Gray Iron Foundry,"* Transactions A.F.A., vol. 41, pp. 144-157, 1933.

the sand to a storage bin of a capacity a little greater than the daily total requirement of the shop. By means of a feeder, a measured quantity of sand, determined by the size and type of the batch mixer, is taken fro mthe storage bin. The content of the measuring bucket is emptied into a muller type mixer and to this batch, new sand, bond, water, seacoal or any other commodity necessary to the predetermined standard (perfect) sand mixture, is added by volume measurement. In the first period of the time cycle devoted to mulling, the materials are thoroughly mixed while in a dry state, then the measured amount of water or perhaps liquid binder is added and the mulling continues for the time required to build up the exact bond required.

11. When this batch is dumped, it passes through a disintegrator into a mobile hopper, which has been lowered into a pit below the mill (Fig. 2), and shoved underneath the disintegrator to avoid spillage. The hopper, which is equipped at the bottom with a hand-operated gate, is raised to the monorail level for delivery into the shop. The hopper is pushed along the monorail on a track extending behind the row of snap flask molding benches, which is the type of operation in plant used to illustrate this description. A hand-operated switch is thrown as the hopper is propelled to its destination and the hopper is pushed into position

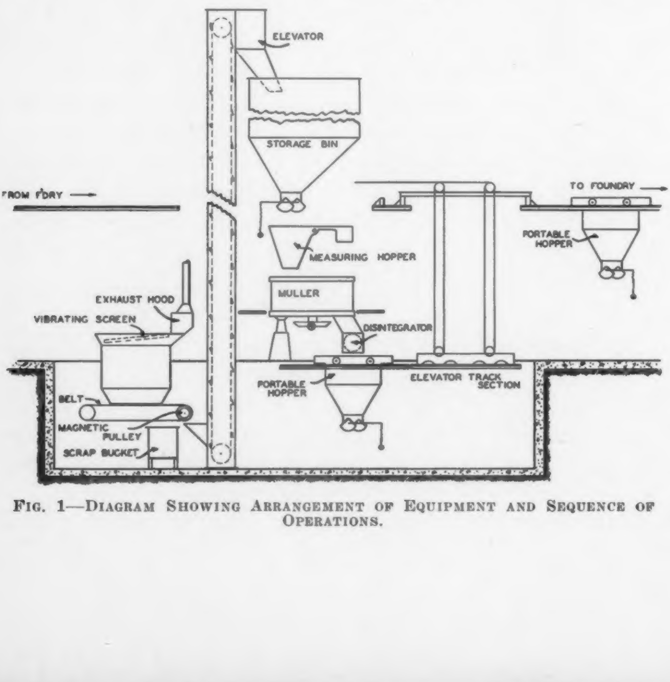

FIG. 1—DIAGRAM SHOWING ARRANGEMENT OF EQUIPMENT AND SEQUENCE OF OPERATIONS.

directly over Jerry's bench. This first hopper of the day, however, was placed in this position before Jerry's arrival. When Jerry arrives he goes to his bench, puts his snap flask in position on his pattern plate, gives a firm pull on the lever of his bin gate, and he is off with the whistle and his full store of vitality to a good start for the day.

12. As the contents of the several bins are depleted, they are shoved back onto the main line by the molder and he pulls into place a waiting bin filled with precisely the same sand mixture with scarcely any delay. Empties are returned to the sand shed by the operator on his return trip after delivering the loaded bin, so that even in this operation of transfer, there is little or no slack motion.

Fig. 2—Hopper Lowered and in Position Under Disintegrator, as Shown in Fig. 1.

FLEXIBILITY

13. Many incidental advantages are to be obtained in connection with this simple system that may be added from time to time as necessity may arise, which in no way can be considered "trimmings", but as actual and helpful cost reducing items. For example, suppose the man next to Jerry is making a mold for a casting that is much heavier in weight and requires a much stronger sand or a mixture in which less moisture is needed than

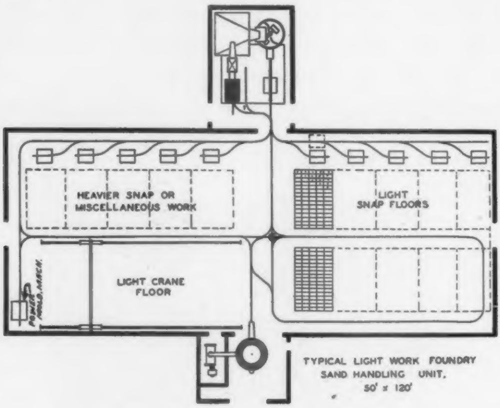

FIG. 3—FLOOR PLAN OF PLANT.

the very light gate of patterns on which Jerry is working (Fig. 3). The man in charge of the batch mixer by varying the proportions of his material quantities, the amount of liquid binder or water introduced, or the time of mulling, can furnish this second bench with an exact duplication of the mix required in each ton or half ton that goes into his particular hopper, even though there have been several tons of sand through the muller between each one of these special batches.

14. Great flexibility also may be obtained in shop layout. Suppose it is desirable to change the arrangement or location of the benches, or perhaps add one or two small high speed molding machines (Fig. 4). The plant might be operating a small traveling crane floor from a floor heap, or a jib crane floor with a fair-sized rollover machine on it. The expense of changing the monorail is very low and the time required is short. A change of monorail to serve any one of these several purposes can be secured

quickly and cheaply and the right sand for the right job becomes just a matter of transportation. In connection with a monorail system of this character for handling sand, it would be unusual if the manager did not utilize it for conveying his iron from the cupola to the molding floors and for removing the castings to the cleaning department.

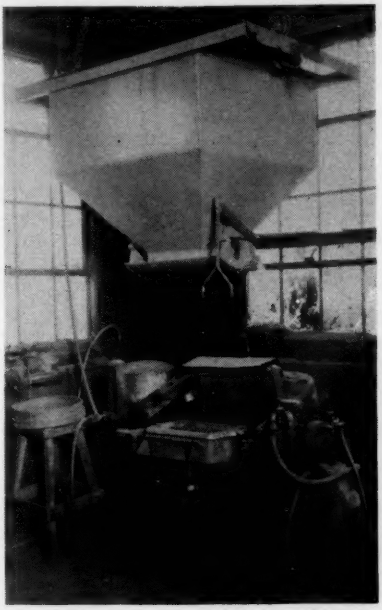

FIG. 4—ONE TON HOPPER IN POSITION OVER POWER MACHINE ON SIDE FLOOR.

15. There is but little time for figures as the installation outlined in this paper has been described in a paper presented in 1933.[1] The savings recorded in that paper have been improved in every department by splendid percentages and the original investment in the sand handling equipment, $12,000.00, was paid out of actual savings in three and one-half years. At the end of three years there has been a total expenditure of less than $200.00 for maintenance.

16. This paper is presented as a review, and not as a technical treatise. The condition confronting the average foundryman today demands that he supply better products at a lower selling price than has ever heretofore maintained in the foundry

industry irrespective of classification. It seems, therefore, that to continue the conduct of a profitable business, costs must be reduced all along the line; many more pounds per hour per man produced; labor costs per ton lowered, and good castings substituted for scrap. All of these desirable conditions may be and are now being obtained by a mechanically operated sand handling plant designed to meet the needs of the individual small operation. In other words, an ever uniform, properly conditioned sand heap (and this is true if a total as low as 20 tons of sand per day is used for the entire shop) will return excellent results in peace of mind and actual cash savings.

DISCUSSION

E. W. BEACH (*Introductory Remarks in Presenting Paper*): I have attended the mechanical handling sessions ever since this division of our convention program was inaugurated and sessions of a similar character before that time. These earlier meetings were at a period in my foundry experience when I was operating a 40-ton plant and I believe that I was representative of the rank and file of our Association membership, managers, or owners of shops averaging from 30 to 60 ton melts a day. To me in those days it was very interesting, of course, to see the pictures and hear the descriptions and discussions of mechanical equipment required to produce, for instance, one automobile motor block per minute. I went out from those meetings with the hope that some day I might garner sufficient pennies to possibly do something of the same sort in a smaller way. However, I did not leave the sessions with anything which gave me an opportunity to go back to my small foundry and with the use of a few thousand dollars approach either the speed or low cost of the operations which were so interestingly described.

These experiences caused me to suggest to our program committee that this year's session be devoted to papers dealing with the possibilities in mechanical handling for the small foundry, embracing the two great essentials in the matter of material handling that enter into the costs of low tonnage foundry production; first, the preparation of sand which is widespread in its result as concerns profit and loss in foundry operation and the second, the waste of labor very often found in the operation of changing the cupola by hand. My part in the program for this meeting is the subject of sand handling and I know of no better example of the small sand handling plant than one located in our own city of Muskegon. While this foundry was the subject of a paper in 1933 by Mr. Amos, the designer of the plant and the operator of the foundry, I have asked permission to take it up again as a matter of review.

At the conclusion of his paper, Mr. Beach presented a short motion picture of the salient operations of the plant and also lantern slides of several items of the equipment. The two diagrams, Figs. 1 and 3 of the paper, were explained in detail as to the sequence of operation and methods of handling.

MEMBER: Does the molder carry out his own molds?

MR. BEACH: He does. That question you will find answered in the TRANSACTIONS* of August, 1933, and was one which was asked of Mr. Amos when he presented his technical paper which included cost figures on this same installation. The gentleman who asked the question at that time stated that he was running a shop in which they poured twice during the afternoon and that they put the molds on roller conveyors and ran them out to the back of the floor in accumulated lines so as to simulate a continuous pouring job. The gentleman who asked the question, reinforced with facts and figures, said he found his molders "carrying off" on the large floor were walking 15 miles a day. With a molding operation extending over 7 hours and a total of 7½ tons of iron to pour, continuous pouring is out of the picture.

F. D. O'NEIL[1]: What approximate percentage increase in molding production would you credit this sand handling equipment with?

MR. BEACH: Mr. Amos did not give me any figures on that particular item but he did tell me that the cost of preparing the sand for the individual mold had been reduced about one-half. I think he said that previous to putting in the installation it cost him $24.00 a day to prepare sand and he is now doing it for something like $14.00.

L. G. KORTE[2]: Is there any advantage and what advantage, if any, does one have by moving the hopper over each machine rather than having a stationary hopper?

MR. BEACH: There is no particular advantage except the first cost of your mechanical handling installation. If you install the conveyor belt type of plant and all the equipment and mechanism that goes with it, you will find the bill is going to be a big one, your maintenance will be higher and it will take constant attention in several directions. For one item, you will have a considerable power bill to meet each month. The low cost of installation is what I have tried to bring to your attention in connection with the results to be obtained and the added fact that it will pay out in a short time. From that time on, in addition to the savings which are effected in bonding material by the reduction of the quantity of new sand used, there is also the actual saving of scrap converted into good castings. It is the simplicity of the layout that should appeal to the small shop owner. It is not beyond your reach. You can save yourself a lot of money and a lot of grief; you have the greatest help obtainable in producing good castings, for the foundryman is dependent upon the exact measurement of materials, time and energy to gain this result. If your operator can be taught to follow strict routine, the quality and physical properties of your sand can always be a known quantity in the equation of your foundry problem. If you require a heavy sand on a floor, you can have it. The next 1,000 or 2,000 pounds needed may be entirely different in character of mixture, if desired.

MR. KORTE: What I had in mind was whether the moving hopper had any advantages over the stationary hopper.

MR. BEACH: If your hopper is stationary over your molding ma-

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* Amos, M. A. and Grace, R. W., "*Handling and Conditioning of Sand in a Small Gray Iron Foundry*," TRANS. A.F.A., vol. 41, pp. 144-157 (1931).

[1] Western Foundry Co., Chicago.

[2] Riley Stoker Co., Detroit.

chine, you must convey your sand to it, which involves, as I have already said, the installation of a belt type of sand handling equipment. The mobile hopper constitutes an economical form of transportation at a low first cost.

H. M. LANE[3]: Mr. Beach, I think there is one point you have not brought out in your description of the plant; the fact that an installation such as you describe requires very little head room. Many old shops have very low truss beams so designed that the installation of belts is wholly impractical. A monorail suspended from the truss solves the problem.

MR. BEACH: Mr. Lane is quite right. The shop in which the installation is located that I have described, has a very low head room. The monorail itself, I think, is only about six inches below the lower cord of a wooden truss.

MEMBER: In reference to the means of agitating the sand under the muller, is there any screening device under the muller or is there some other means of agitating?

MR. BEACH: The type of muller used in this plant is a well-known make. The screen that is used for the return sand is very small, it is only quarter inch mesh. After the sand has passed through the various hoppers, it comes down in a very dry state as it passes into the mill. The bonding material is added and mixed in the dry state, then, after adding moisture, it is mulled about two minutes and passes through the regular disintegrator furnished with the muller. The sand comes out in a condition perfect for the production of small smooth castings. The castings are smooth and good, in many respects, better, than some steel stampings. They are typical of lock and hardware castings in finish. I presume Mr. Amos governs his quality with the type of sand with which he rejuvenates his system. Incidentally, in his paper he stated that they had been using between four and five carloads of new sand a year before the installation of this sand handling plant. He told me recently, that under present conditions of about the same tonnage he had only used a little over a car and a half of new sand for the year, as compared with his previous requirement of five cars.

MEMBER: At what point is the new sand added?

MR. BEACH: At times it is put in through the screen at the shakeout if the return sand is very hot and used to temper the sand going into the storage bin. At other times, according to the batch required, it is introduced on the platform by the operator.

MEMBER: Will the author explain the method of removing the fines?

MR. BEACH: Originally there was a natural draft ventilating opening half way up the elevator shaft, which I believe took out too much fines from the sand. Now the removal of the fines is governed at the shakeout with a hood which curves over the screen. The quantity of fines removed is controlled by the velocity and volume of air according to the necessity of the mixture.

CHAIRMAN J. THOMSON[4]: In regard to that $200 maintenance item:

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[3] Grosse Isle, Mich.
[4] Continental Roll & Steel Foundry Co., East Chicago, Ind.

did it just cover the monorail only or the monorail and the sand mill, or what?

MR. BEACH: Mr. Amos made the statement that outside of several small parts that had failed from breakage, that his actual cost of maintenance was just below $200.00 for the whole system.

MEMBER: Does Mr. Amos use any clay bond?

MR. BEACH: He introduces from time to time green bond, this I presume is in the nature of bentonite.

CHAIRMAN THOMSON: Before this discussion is ended, I want to have our Vice Chairman say a few words on the subject.

VICE CHAIRMAN P. DWYER[5]: I have very little to add to what Mr. Beach has said. He has covered the subject in a very thorough manner. There was only one point I did not quite understand. When he mentioned carrying those hoppers over the different parts of the shop, did he mean one hopper was sent to each machine and would remain stationary until empty?

MR. BEACH: The hopper remains over the bench. That is the molder's supply of sand until it is exhausted. When empty he shoves the hopper out of the way. The man from the regenerating plant has a filled hopper waiting on the sidetrack and shoves it into place. In the interval, the man at the bench has made perhaps two molds with the shovel from the spill on the floor; it keeps the floor clean around the bench. Mr. Amos uses ten hoppers in his system.

VICE CHAIRMAN DWYER: Material handling is a very important subject. There is no use opposing it and saying you don't have to have it. There is no use in maintaining a reactionary spirit. Mechanical handling of material has come to the foundry and it is going to stay and the foundry is going to become more mechanical as the years go by and we must adapt ourselves to it. The only thing to do is to adapt it in a manner that will conform to our pocketbook and save something in the operation.

This installation described by Mr. Beach seems to be the ideal installation for the average small foundry. Out of a total of over 5,000 foundries in the United States and Canada at present, the great majority are still small foundries casting less than ten tons a day. Under normal conditions these shops require mechanical handling equipment. Up to now it has only been applied to the very large shops.

The big shops try something out and if it works, fine. If it does not work, "Well, we'll try another one; we'll build a bigger one and a heavier one." The smaller foundries with limited amount of capital have always felt the installation of mechanical equipment was not justified. In many cases they said, "We have a number of men working here. They have become accustomed to tossing up their own sand, putting up their own molds and shaking them out." That has been the regular routine. Several years ago, when there were not enough molders to go around, the larger shops found a high degree of mechanical skill was not required. They had to teach less skilled men how to do certain jobs.

That condition gradually is invading other shops. The supply of

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[5] The Foundry, Cleveland, O.

skilled men gradually is dwindling. The older men are dying off and no young men are coming in to learn the molding trade after the old fashion. In fact, it is not necessary. Certain classes of castings require molders of the highest skill. But a vast quantity are made by men who require little or no special training. More and more the work is being done by mechanical means. And it will continue to be done that way. That is the direction of the tide of progress and you can not stop it. It has been the same in other industries and it will be the same in the foundry industry. Necessity of keeping inside the line that separates the black and the red pages on the ledger has brought it about, and it is going farther in that direction all the time.

An adaptation of the method described by Mr. Beach has been introduced in several jobbing shops. One Cleveland foundry uses the basic idea of preparing all the sand independently at one time and distributing it. I think that general idea will be adopted by all shops eventually because there is no other way of getting the sand where they want it when they want it. The old method of the man preparing his sand by the shovel will be done away with altogether. One of the reasons is that the men who prepare the sand at present are not as skilled as they formerly were. Another reason is that the molders' wages and helpers' wages are different. If you can get a helper to throw up sand for $2.00 why pay $7.00? If you can get the job done for 50c with a piece of mechanical equipment, why get anybody to do it? Unfortunately, it seems to be a heartless procedure. It means three or four more men in the bread line for every machine you put in, but no matter what you think about it or how you feel about it, that is the trend in the foundry at the present time, to get as much work done as possible by mechanical means. The only question is whether the volume of work in the shop will stand the cost of mechanical equipment that will pay for itself over a reasonable period of time. This shop described by Mr. Beach runs 7 tons of castings per day on an investment of $12,000, with a maintenance cost of $200.00. If it pays for itself in 3½ years, it is a very, very worth while installation.

Notes on the Production of Cupola Malleable Castings

By F. B. Riggan,* Birmingham, Ala.

Abstract

While the greater part of the tonnage of malleable iron is made by the air furnace process, the cupola furnace method is used extensively in the production of malleable iron for fittings, especially in those plants desiring continuous pouring. Through metallurgical and other means of technical control the quality of the cupola product has been much improved in recent years. The author discusses the advantages and disadvantages of cupola melting. Raw material in the form of steel scrap, remelt, pig iron and coke are carefully controlled and stored. Charging is described as is the operation of the cupola. Melting control by temperature measurements is practiced and fluidity is checked. Physical tests of the iron are made as a matter of routine and data on these are reported. The author discusses the questions raised in regard to machinability.

1. Since the beginning of malleable cast iron production in the United States, a variety of furnaces has been used for melting the iron. Probably the earliest furnace used was the crucible, from which the iron was taken out in the liquid form without refining. The final analysis was practically identical with that of the mixture going in the furnace. This method, although ideal from a metallurgical standpoint, did not fit into the changing conditions of mass production and competitive costs.

2. Today, probably 90 per cent of the total tonnage of malleable cast iron produced is melted in the air furnace, open hearth, electric furnace, or one of the duplexing processes. A great portion of the remaining tonnage is melted in cupolas by those plants in which it is desirable to maintain continuous operation.

3. When the writer was asked to comment on some of the

* Metallurgist, Stockham Pipe Fittings Company.

Note: This paper was presented at a session on Malleable Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

practical aspects of the manufacture of cupola malleable at his plant, his attention was called to the lack of literature on this subject. A survey of published literature on cupola malleable revealed the fact that, with the exception of a few very general articles in this country in the FOUNDRY and of a brief mention in the symposium on Malleable Iron Castings,[1] no modern data were available.

4. In 1926, twenty-six German foundries sent in data on cupola malleable to the Kaiser Wilhelm Institute for Iron Research, at Dusseldorf, at the suggestion of the German Engineering Society.[2] These data, which covered malleable with 46,000 lbs. per sq. in. tensile and 3.5 per cent elongation, are still quoted year after year, for the simple reason that information such as that shown above is practically all that is available.

5. The situation in regard to information published and contained in various handbooks in the malleable industry has been similar to that in the gray iron industry. For many years handbooks on mechanical engineering gave the strength of gray iron castings at very low figures, sometimes as low as 14,000 lbs. per sq. in., although castings were actually being sold on a minimum basis of 60,000 lbs. per sq. in.

6. It is significant that such technical and metallurgical advancement made the past few years, with the many refinements in cupola operation and closer laboratory control methods, has resulted in cupola malleable iron much higher in quality than that obtained several years ago. The writer believes that a brief paper depicting some of the practical aspects governing the routine practices and observations of results covering many thousand test bars and analyses may be a worthwhile contribution to the published information on cupola malleable cast iron.

ADVANTAGES AND DISADVANTAGES

7. Although having somewhat higher carbon and lower test bar strength than the normal air furnace product, cupola malleable iron has many qualities that fit it peculiarly to the continuous production of light castings. The high fluidity of cupola iron is of great importance in running small thin castings, as will be discussed later in this paper. The advantage of low shrinkage

[1] *Symposium on Malleable Iron Castings*, 1931. Published jointly by the American Foundrymen's Association and the American Society for Testing Materials.

[2] Dr. Kalpers, Foundry Trade Journal, April 4, 1929.

with reference to sound castings is obvious when dealing with castings subject to internal pressure.

8. The accelerated cooling of the castings from liquid metal in the mold to black heat is advantageous in respect to primary graphite, grain size, and annealing. In the plant with which the writer is connected, the interval of time between the pouring of the mold and shakeout is very important and carefully regulated.

9. A yield point of about 70 per cent of its tensile strength makes for greater rigidity and bursting strength.

MIXTURES AND RAW MATERIAL

10. Steel scrap is obtained from local structural and fabricating plants and is bought according to the following specifications:

Structural steel scrap,
Size 24 in. length maximum
$\frac{1}{4}$ in. thickness minimum
100 lbs. maximum weight of single piece,
free from wrought iron.

11. When cars of this steel arrive in the yard, they are inspected by the metallurgical department. The car is not moved until the unloading foreman has an order from the laboratory consigning this car to its particular bin. Fig. 1 shows the arrangement of the storage bins and cupola charging layout.

12. Cars containing small pieces, such as punchings or clippings, are sent to the steel foundry for use in the electric furnace. Those containing any wrought iron, or pieces thicker than one inch, are sent to the gray iron foundry bins. That steel accepted as suitable for melting stock in the malleable cupolas is unloaded by means of an overhead magnet crane, into a series of four large sloping bins. Here a further grading takes place. In one bin the large new stock is segregated so far as this can be done conveniently with the magnet.

13. Two bins hold the medium, or most satisfactory, sized pieces, and the fourth bin holds the scrap that is so thoroughly mixed that no further separation is possible with the magnet. The ideal size, as related to our charge and mechanical equipment, would be a 4 in. angle, $\frac{1}{2}$ in. thick and 18 ins. long. Stock of this size is most suitable for fast, hot melting. Steel scrap usually constitutes a considerable portion of our total charge.

Remelt

14. Our remelt has been cleaned and is free from sand. All castings which are scrapped subsequent to annealing operation are melted in the gray iron mixtures.

Pig Iron

15. A local low phosphorus pig is used in varying amounts for the purpose of holding the carbon in the charge constant. Experience has shown that this can be done more uniformly by varying the amount of pig iron in the charge than by varying the steel. This pig analyzes: Si., 2.00 per cent; Mn., 1.50 per cent; S., 0.04 per cent; P., 0.40 per cent; and C., 4.25 per cent. The above iron charge is considered ideal for mechanical charging,

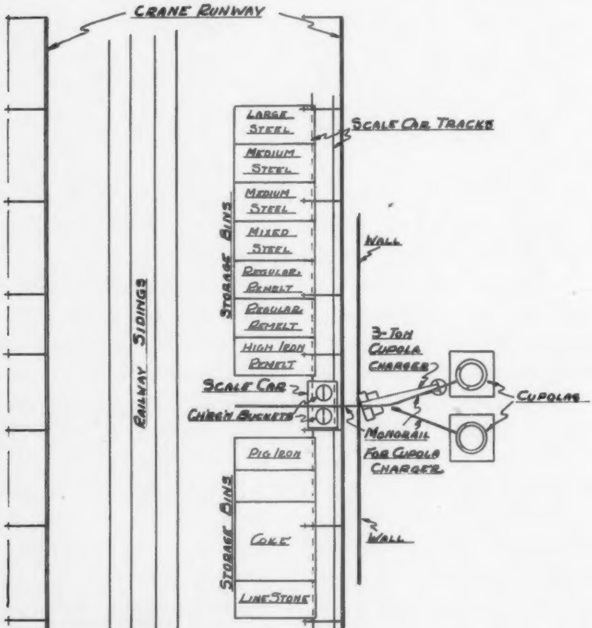

FIG. 1—LAYOUT OF STORAGE BINS AND CUPOLA CHARGING ARRANGEMENTS.

since there is a minimum spread in silicon analysis of the components of the charge.

Coke

16. Of all raw materials entering the cupola, coke is considered most important. Yet, peculiarly, our yard stick for measuring the desired quality in the material is very crude. Although we have a standard set up of running rather complete analysis on this material, including shatter, combustibility, ash, microscopic examination of cell structure, etc., our most dependable check so far as performance is concerned, is watching the cars unloaded. Large sized, gray colored, dense structure with few "lady fingers", black heads or fines, insure best performance if the chemical analysis is within range.

17. Until four or five years ago, we felt that we had to have at least a portion of our coke charge consist of petroleum or pitch coke, in order to get consistent high temperatures. Since then, we have been able to standardize on a local by-product coke made from local coal seams. Coke from a particular mixture of this coal has the following analysis:

Volatile Matter	.40 to 1.00 per cent.
Ash	9.00 to 9.60 per cent.
Fixed Carbon	89.75 to 90.50 per cent.
Sulphur	.60 to .63 per cent.
B.T.U.	13,000 to 13,400.
Combustion	
Ignition Temp.	1030 to 1060 degrees Fahr.
Total Rise	315 to 335 degrees.
First 250 Degrees	1.50 to 1.75 minutes.
Total Time	2.75 to 3.25 minutes.

18. The relatively slow burning coke seems to give best performance in our particular operation. Incidentally, some of the coke that worked less satisfactorily analyzed very closely to the above specifications. In general, the coke that gave trouble would vary from the above averages, as follows: Volatile, higher; ash, lower; carbon, same; sulphur, higher, and for combustion figures, total rise, lower; first 250 deg., lower; total time, less. In this connection it must be remembered that these are our own tests for our own highly specialized product and it should not be inferred that cokes varying from above are not good foundry coke.

Mixtures.

19. The usual mixture consists mostly of remelt, steel scrap and pig iron,—the proportions of these are regulated in accordance with the amount of remelt available and other variable conditions. The analysis of the castings is controlled by the addition of proper amounts of silicon briquets or manganese briquets.

Briquets.

20. Silicon and manganese are added to the charge in the form of briquets. By using the silicon briquet, we were able to cut our silicon going into the charge 5 per cent due to the pro-

FIG. 2—ARRANGEMENT FOR PUTTING BRIQUET CHARGE IN ADVANCE OF TAKING TO CUPOLA.

tective nature of the binder in preventing oxidation of the silicon. Not the least of the benefits derived from the use of these briquets is that of being able to count the briquets on each charge, rather than depend on the accuracy of small weighing devices kept around the charging platform.

21. Fig. 2 shows a convenient arrangement for putting up the briquet charge ahead of time. This is of benefit particularly when in our afternoon pouring the mixture is changed for the heavier sectioned castings. To prevent any possibility of briquets from one charge falling in those of the preceding charge, due to charges hanging up in the buckets, the briquets are placed in the bottom of each succeeding coke bucket. This places the briquets on top of their proper charges.

Charging

22. The charging buckets are placed on a multiple beam scale car. Each beam is numbered corresponding to a particular iron material bin. The first four beams are for steel scrap as shown in Fig. 1. As may be noted in Fig. 1, the first beam is for large steel, the next two beams are for medium sized pieces, and the fourth beam is for mixed steel scrap. The next three bins are reserved for remelt. Return sprues and risers from the heavy floors are kept separate from the regular remelt. So far as possible, each day's remelt is kept in a separate bin and used completely before changing over to that made the following day. Bin 8 is used for pig iron.

23. A charging bucket of conventional type insures accurate distribution of material in the cupola.

Cupola Operation

24. In starting the cupola about two-thirds of the bed coke is burned by natural draft to a good cherry red. By proper manipulation of the tuyere doors this burning through can be done very uniformly. The last third of the coke is then added, making a total depth of bed of 50 in. Four or five charges are lowered into the cupola and the blower is started immediately. Nine minutes is the usual time for the first iron at the tap hole. While this iron is melting, the number of charges in the cupola are increased to nine, and the stock is usually held at this level for the remainder of the heat.

25. For the size cupola we use our variable speed blower is usually set at a definite figure to give the required melting rate and the desired pressure is obtained by regulating the height of stock in the cupola.

26. On these front slagging cupolas, the iron runs continuously into large teapot type mixing ladles. The slag level inside the cupola can be varied as desired by raising or lowering the height of the over-flow slag notch. When it is desired, as much as two inches of iron can be held in the cupola by raising or lowering the dam back of the slag cut-off. Giolitti[3] in a recent comment on cupolas in general makes the statement that the syphon shaped, tap hole brick device is the most important cupola development in twenty years. In the writer's opinion, the front

[3] Metal Progress, March 1935.

slagging device, located outside the cupola has additional advantages over the tap hole brick. In our usual routine practice, an additional control on carbon is found by proper manipulation of this slag cut-off spout. The molten slag runs from this cut-off down a covered trough into large iron pots, which are spotted, between two cupolas, on a narrow gauge track.

27. We figure the slag is derived as follows:

Per cent slag	From
28.0	coke ash
40.0	lime rock
18.0	cupola lining
5.5	iron and manganese
3.0	briquet binder
5.5	silicon and other losses

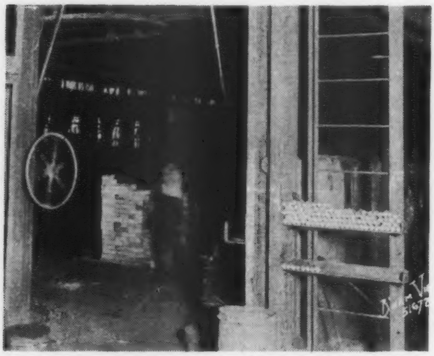

FIG. 3—VIEW IN FOUNDRY SHOWING TEST BARS IN RACK.

The slag weight is approximately 6½ per cent of the total iron charged.

28. Fused soda ash added to the back of the tilting forehearth in the amount of approximately six lbs. per ton of iron lowers the sulphur from about 0.135 to about .100 per cent.

Melting.

29. *Pouring:* Spout temperatures range from 2790 to 2820 degrees Fahr. Optical pyrometers are used. These are frequently standardized and the temperatures are accurate, as has been shown by an occasional check with thermo-couple pyrometers. Test sprues 2 in. in diameter, 8 in. long are poured at 4 to 5 minute

intervals (Fig. 3). These bars are quenched in water after cooling in sand for 6 minutes. The fracture gives the experienced operator an accurate control of his metal. There checks are further substantiated by hourly chemical analysis. The wall thickness on all castings poured with this type of iron ranges from a minimum of 3/32 to a maximum of ¼ in.

30. Standard A.S.T.M. test bars are poured at one hour intervals. The analysis of these bars is checked immediately from samples obtained by pounding up shot from this metal. This method is checked periodically by drilling samples from corresponding large test blocks.

31. Starting with a temperature of 2800 degrees Fahr. at cupola spout, the iron runs first into the back of the mixing ladle where it is desulphurized and then is titled by remote control into 100 pound pouring ladles.

Fluidity.

32. A very good idea of the fluidity of the metal as related to very thin castings may be had by observing the manner and time of filming over of the top of the sprues. Occasionally, on days with high humidity, this filming over of the test sprues is a matter of very few seconds. The breaks in the film will occur very fast and will be of short duration. The appearance of the test bar fracture, however, does not seem to be affected as would be expected in the case of slight oxidation.

33. Incidentally, this occasional trouble in lack of fluidity on high humidity days, as evidenced by the special fluidity test and filming over characteristics, has been considerably reduced since we started adding our silicon in the form of briquets. The writer is now interested in an investigation to determine, if possible, just what influence silica may have with the above mentioned phenomenon, but as yet has no conclusive data.

Physical Tests.

34. Standard ⅝ in. tensile test bars are cast in duplicate each hour, each bar having the month, date, and hour cast on each end. In the same mold is cast a 5 in. wedge, 1 in. wide, ⅜ in. thick at one end, tapering down to ⅛ in. at small end, and a 1 in. x 1 in. x 5 in. square bar. The wedges are annealed, broken, and filed according to date, with the corresponding ten-

sile and square hard iron bar. Years ago, the wedges were galvanized and broken as a check on deterioration. But since no indication of galvanizing embrittlement has been noticed in any of these bars in the past five or six years, it is now standard practice to include this, with our routine impact tests on actual fittings taken from each annealing pot and galvanized. A set up for this test is shown in Fig. 4.

MACHINABILITY

35. Machinability can be checked fairly close on the fittings since the hardness and microstructure of the cutters are controlled by the laboratory. Complete data on fittings tapped between grinds is available for each size and each machined speed.

Effect of Machining Off Outside Skin of Cupola Malleable Test Bars.

36. Letters arrive, almost daily, from prospective users of malleable iron, seeking information on some phase of the relation between physical properties of the surface and center portions of malleable castings. With this in mind, the metallurgical department has had several hundred test bars machined from the regular $\frac{5}{8}$ in. diameter to $\frac{1}{2}$ in. diameter.

37. Each machined bar had its companion $\frac{5}{8}$ in. diameter

FIG. 4—ARRANGEMENT FOR MAKING ROUTINE IMPACT TESTS ON FITTINGS.

unmachined bar, for comparison. The average results were as follows:

	Elongation Per Cent	Yield Point Lbs. per sq. in.	Tensile Strength Lbs. per sq. in.
Unmachined 5/8 in. bar............	9	34050	48000
1/2 in bar machined from 5/8 in....	9½	34200	47900

It is believed that so far as yield and strength are concerned, the difference is negligible. The slight difference in elongation is probably due to the uniform cross section and surface smoothness of the machined bar. These results are not in conflict with those reported very briefly in the A.F.A.-A.S.T.M. Symposium on Malleable Iron.

Material Strength of Cupola Malleable Fittings

38. The average load required to pull in two a 3/4 in. union made at our plant and tested in accordance with Navy Specification 45-U-3-C is 17,500 lbs. The maximum variation on over two hundred 3/4 in. union tested was 2,000 lbs. This is well above the navy specification which calls for 10,600 lbs. on this particular size and class.

39. Water bursting strength on ells of this same size, standard weight, averages over 8,000 lbs. per square inch.

Conclusion

40. Some years ago the production of malleable castings by the cupola process was attended by many difficulties. Since the era of metallurgical control, the picture has changed to a very great extent. Today castings are being made by the cupola process with definite standards for composition and analysis. Some of the great helps in producing these castings today are accurate and quick chemical analysis, reliable optical pyrometers, greatly improved mechanical equipment such as chargers, multiple beam scales which insure accurate composition of the charge, variable speed motors with controlled blast, physical testing equipment, and frequent furnace tests. By such means we are able to make a uniform malleable product with excellent machinability, with ample physical properties, and with uniform integrity.

DISCUSSION

In absence of the author, Mr. Riggan's paper was presented by H. C. Aufderhaar, Electro Metallurgical Co., Chicago.

DR. H. A. SCHWARTZ[1] (*Submitted in Written Form*): Mr. Riggan's contribution to this subject is the more welcome because of the great scarcity of information, to which he points in the field of discussion. It might be added that, for those familiar with German, a rather thorough modern study of German cupola practice in the malleable art is to be found in Schüz and Stotz "*Der Temperguss*", Springer, 1930.

Having in mind the great need of further literary treatment of the cupola melting art, it is unfortunate that Mr. Riggan, or perhaps his principals, did not deem it expedient to go into greater detail as to the chemical composition and physical properties of cupola metal as produced under the circumstances which he has described. It would seem that quantitative data showing the scatter of the physical properties, along the same lines as included for air furnace and similar metals in the *A.F.A.-A.S.T.M. Symposium on Malleable Castings*, would have been highly welcome.

The present commentator has no personal knowledge of the manufacture of pipe fittings; it seems somewhat obvious, however, that cupola malleable has, by actual use, demonstrated its great fitness for this application at least in the vast majority of cases. From the physical properties given on page 437, one is led to assume that cupola iron is admittedly somewhat weaker than the lower carbon grades of air furnace iron. It would seem that this need be no obstacle to the publishing of data describing correctly those types of cupola iron which are known to produce pipe fittings of a quality both as to soundness and strength demanded by the trade. The present writer has frequently pointed out in other connections that the strongest product is not necessarily the best for all purposes. Under these circumstances, the suggestion is offered that the manufacturers of pipe fittings for the general trade might do better to educate the engineering public into an adequate appreciation of the fact that metal of the properties which they produce does make adequate pipe fittings than by showing reluctance in the publication of physical data bearing on their product. The manufacturers of fittings can not be blamed for using their own best judgment as to the data which they desire or did not desire to publish. We should all welcome as much information as can be given us even if we do not get all the information we want. It is desired to point out, however, that both the metallurgist and the engineer would no doubt be greatly interested in more complete quantitative information as to strength, elongation and precision of chemical control than has been included in the present paper. If Mr. Riggan and the Stockham Company could be persuaded to enlarge upon the present contribution along the line suggested the information would be most welcome.

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[1] Manager of Research, National Malleable & Steel Castings Co., Cleveland, Ohio.

H. W. MAACK[2] (*Submitted in Written Form*): For purpose of discussion, Mr. Riggan's paper can conveniently be divided into two phases, the melting and casting of the iron, and the chemical and physical characteristics of cupola malleable iron. The author presents both aspects of the subject in considerable detail.

In his account of the particulars of selecting and testing of the materials that make up the cupola charge, Mr. Riggan reveals the precautions taken to secure melting at a steady rate, iron of uniform temperature and composition. Such control is probably typical of present day cupola practice in the production of cast iron of various kinds for especially exacting requirements for the particular product under discussion and others, in the automotive industry for example.

Concerning the characteristics of cupola malleable iron, these are uniquely well suited to the product for which it is used almost exclusively, namely, malleable pipe fittings. Besides the obvious advantage of the cupola process for continuous production, the castability of the iron, embracing as it does good fluidity, low freezing point, and comparatively low shrinkage, make it especially suitable for pouring castings of thin section. These qualities are obtained largely as a direct result of the content of carbon in the iron although silicon has an influence also. Saeger and Ash* report measurements of solidification shrinkage which indicate that this decreases as the content of carbon or silicon or both increase in the molten iron. It becomes immediately apparent that a lower carbon iron, requiring more generous feeding to insure soundness, does not lend itself as well as cupola malleable to the requirements for the production of large quantities of small castings with thin sections.

The strength and ductility of cupola malleable iron are not as impressive as those of malleable iron of lower carbon content. That they are adequate for the purposes to which the iron is put, is shown by the continued use of the product. Quoting from the *A.S.T.M.-A.F.A. Symposium on Malleable Iron Castings*, 1931, page 61: "However, a casting must be judged, not merely on physical properties of the metal, but upon other less tangible considerations, summed up, perhaps by serviceability of the casting in the use for which it is intended."

DR. E. G. MAHIN:[3] It has always seemed to me unfortunate that in connection with malleable cast iron we make a tensile test upon a cast bar without machining, where with practically every other type of material we are so very particular to do the machining just as well as we possibly can, not only as to uniformity of cross section, but as to smoothness of surface. I suppose it is because the skin of decarburized metal exists on the casting when it is used and so we want it on a test bar. Apparently, it does not make much difference in the test. Such tests as we have made in the Notre Dame laboratories also would indicate this to be true.

It seems to me that the reason it is desirable to machine these cast bars before testing is not so much because the metal will be stronger

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* ASH, E. S., AND SAEGER, S. M., JR., "*Shop Method for Determining Volume Changes in Cast Iron During Casting,*" TRANS A.F.A., vol. 40 (1932), pp. 188-195.

[2] Crane Co., Chicago.

[3] Professor of Metallurgy and Head of Department, University of Notre Dame, Notre Dame, Ind.

or weaker, if we want to find that out, as it is to produce results that may be considered as having a higher degree of precision. If we examine these test bars as they come through, we shall find that the surface is not uniform, it is not smooth, there are depressions and sometimes there are fins on the bars. These can be ground off, of course. Frequently, the cross section is more or less elliptical instead of circular, and sometimes there is a little "fault" in a specimen. Now, in making a test on a bar of that general variability, it does not seem to rank among what we might call precision tests. I should like to see these bars machined and smoothed just as we do with any other alloy, unless we want to excuse the lack of care on the supposition that malleable iron is not uniform anyway and that there is no use in attempting to obtain very accurate results. I do not think anyone wants to make that admission.

DR. J. T. MACKENZIE:[4] In regard to Dr. Schwartz's suggestion that some more physical data might well be included in this paper, I had already suggested to Mr. Riggan that some statistics would be advisable. So we got together and made a statistical analysis of some 390 bars of the regular production of the last year or so. We calculated the average and standard deviations for those bars for strength, yield point and elongation. Mr. Riggan is giving these in his reply to this discussion.

D. M. MCLAIN:[5] Mr. Riggans paper, with the data added is very interesting but I believe the members would like to know the percentages of steel used.

Perhaps it may interest you to know that, for light sections such as pipe fittings, we use from 10 to 20 per cent steel; for medium castings, such as automotive tools, jacks, wrenches, pliers, hammers, and hatchets, 20 to 40 per cent steel; and for connecting rods, crank shafts, sledges, anvils and so forth, 30 to 50 per cent steel.

The chemical composition will range within the following limits:

Element	Per Cent
Total Carbon	2.10 to 2.65
Graphitic Carbon	0.90 to 1.40
Combined Carbon	0.75 to 1.30
Silicon	0.60 to 1.15
Sulphur	0.08 to 0.15
Phosphorus	0.08 to 0.20
Manganese	0.35 to 0.55

In a number of analyses, the carbons are about evenly divided; graphitic carbon 1.30 per cent and combined carbon 1.28 per cent. Owing to the nature of the product, it is essential that the pearlitic structure be maintained.

The tensile strength varies with the amount of steel but is seldom less than 45,000 lb. per sq. in. for the low and up to 65,000 lb. per sq. in. for the high.

F. B. RIGGAN (*Submitted as a Written Closure*): In answer to Dr.

[4] American Cast Iron Pipe Co., Birmingham, Ala.
[5] McLain's System, Inc., Milwaukee, Wis.

Schwartz's request for quantitative data showing the scatter of the physical properties along the same lines as those shown in the *A. F. A.-A. S. T. M. Symposium on Malleable Iron Castings,* the writer has hurriedly listed the last few hundred test bars, divided into cells:

Yield Point, lb. per sq. in.	No. of Bars
30000–30499	3
30500–30999	4
31000–31499	12
31500–31999	21
32000–32499	21
32500–32999	24
33000–33499	33
33500–33999	36
34000–34499	24
34500–34999	36
35000–35499	9
35500–35999	12
36000–36499	6
36500–36999	18
37000–37499	9
37500–37999	6
38000–38499	3
38500–38999	3
39000–39499	1
39500–39999	1
Average 34020 lb. per sq. in.	284

Tensile Strength, lb. per sq. in.	No. of Bars
40000–40499	3
40500–40999	3
41000–41499	8
41500–41999	6
42000–42499	5
42500–42999	10
43000–43499	9
43500–43999	11
44000–44499	32
44500–44999	27
45000–45499	27
45500–45999	20
46000–46499	40
46500–46999	35
47000–47499	30
47500–47999	37
48000–48499	35
48500–48999	15
49000–49499	5
49500–49999	3
50000–50499	1
50500–50999	4
51000–51499	8
51500–51999	5
52000–52499	2
52500–52999	3
53000–53499	2
53500–53999	2
54000–54499	1
55000–55499	2
Average 46400 lb. per sq. in.	391

Per cent Elongation	No. of Bars
5–5.9	20
6–6.9	52
7–7.9	90
8–8.9	120
9–9.9	66
10–10.9	32
11–11.9	11
Average 8.3	391

Analysis of annealed malleable castings:

Carbon, Per Cent........	2.50 to 3.00	Average 2.70
Silicon, Per Cent........	0.70 to 1.10	" 0.90
Mn., Per Cent...........	0.40 to 0.60	" 0.50
P., Per Cent.............	under 0.20	" 0.065
S., Per Cent............	0.15 to 0.25	" 0.170

Deviation reported according to the recommendations of the Committee on Presentation of Data (1931 A.S.T.M. Proceedings):

Yield	Tensile Strength	Elongation
$n=284$	$n=391$	$n=391$
$\bar{X}=34020$	$\bar{X}=46400$	$\bar{X}=8.3$
$\sigma=1910$	$\sigma=2590$	$\sigma=1.4$

After the paper had been preprinted, the author's attention was called to the fact that the words "as cast" might cause some confusion as to the heat treatment or lack of heat treatment of the standard bar. The words "as cast" were struck out and an attempt was made to substitute the word "unmachined" in their place.

The author regrets this typographical slip and particularly the confusion it may have caused readers of the preprint.

The very interesting comments of Dr. Mahin on the question of machining malleable test specimens for greater accuracy will be of special interest to members of A-7 Committee of the American Society for Testing Materials.

Production of Centrifugal Gray Iron Castings in Water Cooled Molds

By H. W. Stuart,* Burlington, N. J.

This paper is a description of the process used to produce cast iron pipe centrifugally in steel molds and some of the newest developments. The fore part of the paper is devoted to a description of the deLavaud process of manufacturing cast iron pipe, explaining in detail the various operations and equipment. The author then describes the apparatus used to coat the steel mold with a pulverulent material to prevent chilling of the outside of the pipe and tells of some of the problems that it was necessary to overcome in the development of the process. The latter part of the paper is devoted to a comparison of the properties of cast iron pipe produced with and without the mold coating.

1. Recently, it was discovered, by N. F. S. Russell and Dr. F. C. Langenberg, of the company with which the author is connected, that cast iron pipe could be cast centrifugally without chill in steel molds used in the deLavaud process. The method by which this has been accomplished and the consequent improvement in the quality of the pipe, resulting from this discovery, will be presented in this paper.

Operation of deLavaud Casting Machine

2. Before describing the process by which chill-free pipe called "super deLavaud pipe", are cast in water-cooled steel molds, it will be necessary to describe briefly the operation of a deLavaud casting machine.

3. The deLavaud casting machine, as shown in Fig. 1, consists essentially of a cylindrical steel mold, mounted on rollers in a water jacket so that it can be rotated at comparatively high speeds by an electric motor. The water jacket also is mounted on wheels so that the entire assembly can be moved by a hydraulic cylinder in the direction of the longitudinal axis of the mold and on a fixed bed inclined slightly to the horizontal. The molten iron is fed into the mold through a trough, also slightly inclined to the horizontal. The trough has a spout, curved toward the side wall

* United States Pipe & Foundry Co.

Note: This paper was presented at a session on Cast Iron devoted to the Centrifugal Casting Symposium at the 1935 Convention of A.F.A. in Toronto, Canada.

of the mold, at its lower end. Molten iron is supplied to the trough by a small ladle of sufficient capacity to make one pipe. In pouring, the ladle is tilted at a uniform rate by an electrically operated tilting mechanism, thus maintaining a constant, uniform pouring rate.

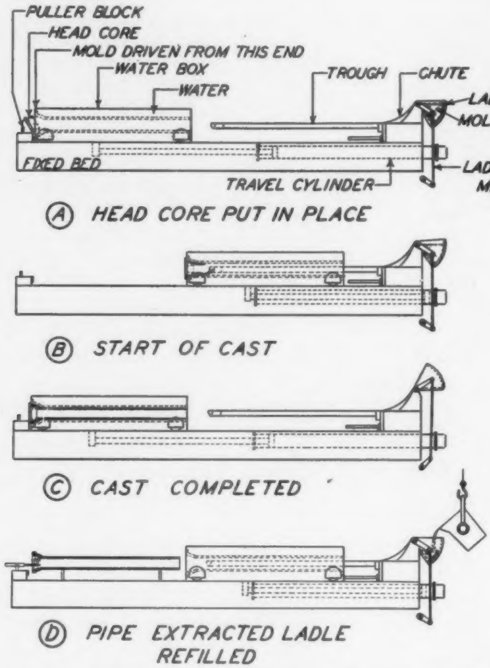

FIG. 1—DELEVAUD CASTING MACHINE, SHOWING DIAGRAMATICALLY THE OPERATIONS IN THE CASTING OF A CAST IRON PIPE.

4. In making bell-and-spigot pipe, it is necessary to insert a sand core into the bell-end of the mold to form the inside contour of the pipe bell. This is done at the lower end of the fixed bed. Following that operation, the mold and its assembly are moved to the upper portion of the fixed bed.

5. When the mold is at the extreme upper end of the fixed bed, it is ready for casting, and the trough extends down the barrel for nearly its full length. After the tilting ladle has been filled by a transfer ladle from the cupola, the machine operator, sta-

tioned at the upper end of the machine, brings the mold up to speed and actuates the tilting ladle.

6. In a few seconds, the iron has filled the bell space and, when this is done, the core setter, stationed at the lower end of the machine, gives the operator a signal to start moving the mold longitudinally down the bed. The stream of iron discharged from the spout flows tangentially onto the surface of the mold, where it is held in place by centrifugal force and forms a homogeneous pipe. The hydraulic cylinder is supplied with a regulated amount

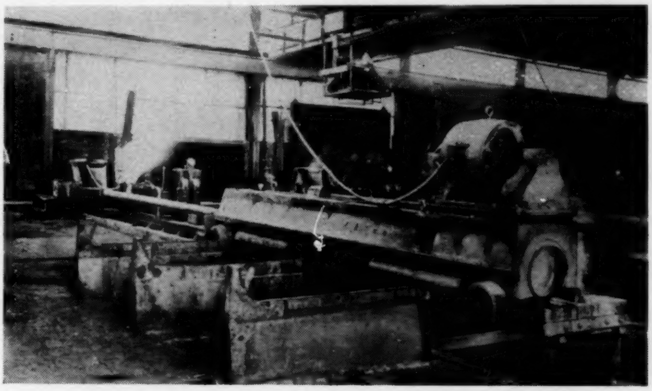

FIG. 2—PHOTOGRAPH OF A DELAVAUD CASTING MACHINE.

of water at a constant pressure; therefore the longitudinal movement of the mold is uniform. Since the speed of the tilting ladle and the amount of water supplied to the hydraulic cylinder can be regulated easily and accurately, the wall thickness of the pipe produced is held within the desired tolerances without difficulty.

7. After the spigot end of the mold has passed the pouring spout, any excess iron is directed into a pig mold, while the pipe mold is kept rotating at its original speed until the casting therein has cooled to approximately 1500 degrees Fahr. The casting is then extracted by anchoring it to the puller block and withdrawing the mold. Having withdrawn the pipe, the mold is ready for the next casting. The entire operation requires from 2 to 10 minutes, depending upon the diameter and length of the casting. Pipes from 3 to 24 in. diameter and 12 and 18 ft. long are now being cast.

8. The arrangement of the casting machine shown in Fig. 1 is purely diagrammatical. Fig. 2 is a photograph of a production casting machine, showing the electric drive, used to rotate the mold. From 1922 to 1934 approximately 85,000,000 ft. of deLavaud pipe were made in the United States by the author's company and one other company which is licensed to use the process. The deLavaud process is patented.

DEVELOPMENT OF CHILL-FREE PIPE

9. In 1930 a research department was established by the company with which the author is connected and, shortly after this, it was found that, by altering the annealing cycle, the quality of the pipe was improved. It was further discovered that, to attain the impact resistance desired, a change in the casting method would have to be made.

10. The results of the tests conducted in the past indicated that if it were possible to produce a casting without the presence of chill, a greatly improved product would result. Knowing the cause of the chill and having determined that the basic principle of the process—use of water-cooled metallic molds—was technically and economically sound, but one thing was left to be done. This was to provide a method for retarding the abstraction of heat from the molten metal.

11. A great deal of thought was given to the application of a refractory wash. There are, however, drawbacks attached to such a procedure. First, it would require a sufficiently long period between the application of the wash and the casting of the pipe to permit the wash to be dried thoroughly. Further, the wash would adhere to the pipe in some places and to the mold in others with the result that the mold would have to be thoroughly cleaned and rewashed to obtain a pipe with a smooth surface. Attention, therefore, was turned to the possibility of applying a dry coating material to the surface of the mold which would either be completely removed with the casting or be of such nature that a jet of compressed air would quickly remove any residue of coating material from the mold.

12. Since cast iron pipe must have a smooth outside surface, it was necessary to perfect a method by which pulverulent materials could be applied to the mold uniformly and conveniently. In addition, uniformity was necessary so that cooling of the molten

metal would be retarded the same amount throughout the casting.

13. In perfecting a method for applying the pulverulent materials, a great deal of experimenting was required. Some of the early equipment for applying the pulverulent material was built very much on the salt-shaker principle. Other equipment consisted of a trough extending the full length of the mold, which contained the proper amount of coating material, and application and distribution were performed by tilting the trough containing the coating material while the mold was revolving. A screw conveyor which fed the powder through a tube fastened to the trough was also tried, but the nature of most of the pulverulent material is such as to pack very firmly and give the coated surface an unsatisfactory lumpy appearance.

Compressed Air Is Carrier

14. When these mechanical means of distributing pulverulent material failed to produce the desired mold coating, compressed air was decided upon as a means of transporting and depositing a coating on the mold. In the use of compressed air as a carrier and a means of distribution, two problems were encountered. First, a means of feeding the pulverulent material into the air stream at a constant rate in regulated amounts had to be devised; second, a means of uniformly distributing the coating material over the mold surface was necessary.

15. Fig. 3 shows a device which was developed to feed regulated amounts of pulverulent material into the air stream at a constant rate. This device consists of a cylinder, the bottom of which is a turntable rotated at a uniform rate independently of the cylinder walls. The powder content of this cylinder is made to rotate as a unit by means of a centrally located agitator and clutch teeth on the upper face of the turn-table. The cylinder is slotted at the top of the turn-table and a knife is affixed in the slot so that a constant amount of powder is pared from the uniformly rotating column. This knife can be adjusted so that the amount of powder pared off can be varied from 20 to 1200 grams per minute. A funnel directs the powder delivered by the knife into an air jet. When the air expands, as it issues from the jet, it causes the powder to become suspended in the air stream. The mixture of gas and powder is conducted through a tube which forms an integral part of the casting machine trough.

16. To distribute the pulverulent material uniformly on the

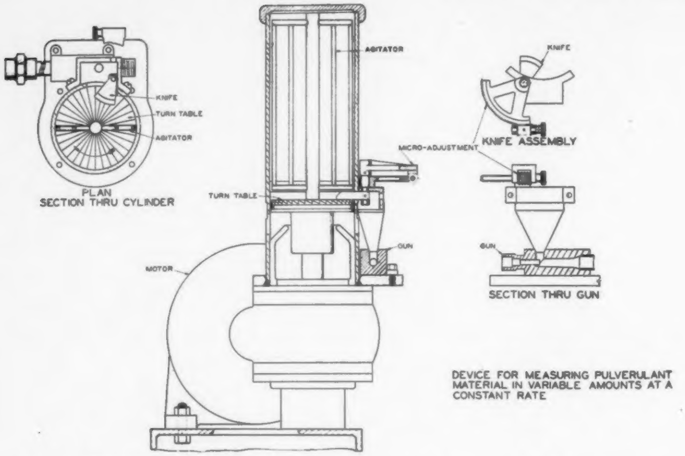

FIG. 3—DEVICE DEVELOPED TO FEED REGULATED AMOUNTS OF PULVERULENT MATERIAL INTO THE AIR STREAM AT A CONSTANT RATE.

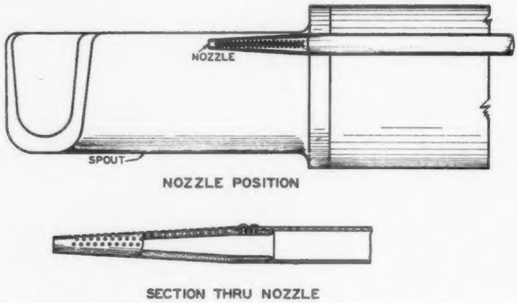

FIG. 4—TOP—DIAGRAM SHOWING THE POSITION OF NOZZLE IN RELATION TO POURING SPOUT. BOTTOM—SECTION THROUGH NOZZLE.

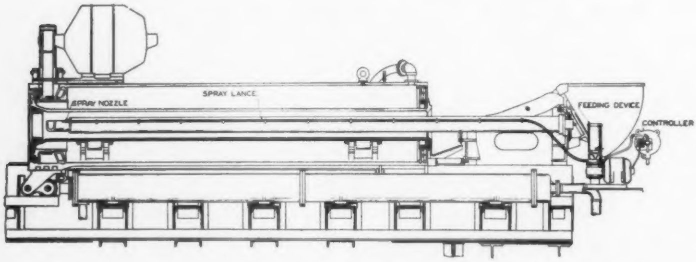

FIG. 5—CASTING MACHINE IN POSITION WITH EQUIPMENT NECESSARY FOR COATING THE MAIN BARREL OF THE MOLD.

mold surface, the nozzle, shown in Fig. 4, was used. One hundred and fifty-seven different nozzle designs were tried before the tapered nozzle shown was adopted. The difficulty in obtaining the proper nozzle design was due to the fact that the suspended material had to be turned through 90 degrees and, at the same time, distributed over a length of approximately 3 in. so that the helix formed as it was applied to the mold, would completely cover the surface.

17. Fig. 5 shows a deLavaud machine in casting position

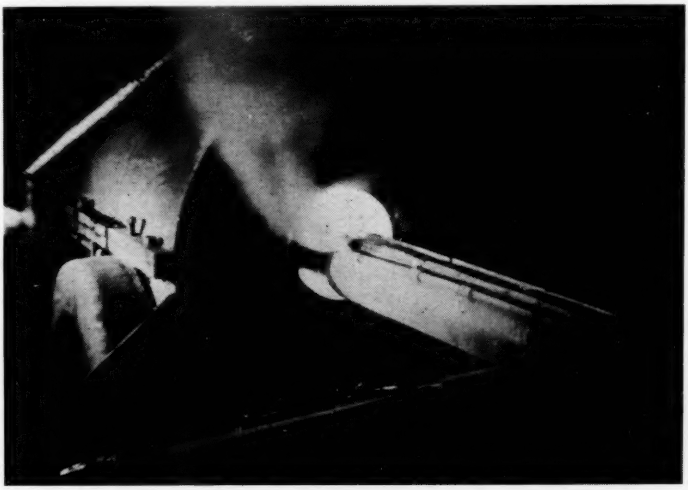

Fig. 6—Nozzle Distributing Coating Material Just Back of the Trough Spout as It Issues from the End of the Mold.

with the equipment required to coat the main barrel of the mold. The feeding device at the upper end of the machine and the distributing nozzle, located just back of the trough spout, are connected by a steel tube that is an integral part of the trough. This equipment in no way interferes with the normal functioning of a deLavaud casting operation, since the machine operator actuates the feeding device and air stream simultaneously with the longitudinal movement of the mold as the pipe is cast.

18. Fig. 6 is a photograph of the spigot or upper end of the mold showing the nozzle distributing coating material just back of the trough spout as it issues from the end of the mold at the completion of the casting operation. The very fine cloud of pul-

verulent material, which is clearly shown, is held against the inside surface of the mold by centrifugal force when the pipe is being cast.

19. The mold coating equipment, shown in Fig. 5, cannot coat the bell portion of the mold due to the nozzle being behind the iron stream. Fig. 7 shows a portable air feeding device, and

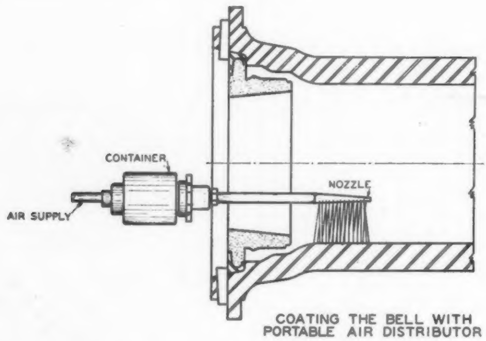

FIG. 7—PORTABLE DEVICE FOR COATING THE BELL PORTION OF THE MOLD.

nozzle, which are used to coat this portion of the mold as the bell core is keyed in place. This operation is performed by the core setter without interfering with the casting operation in any way.

20. As the method of applying a powder uniformly to a deLavaud mold was being developed, progress was also being made in obtaining the proper mold coating material to produce a chill-free pipe with a good surface. It was discovered, early in the experiments with the use of air as a means of transporting and distributing the coating material, that chill-free pipe could be cast with a very small amount of coating material. For instance, a 12-in. diameter, 18-ft. long pipe could be cast chill-free when only 200 grams of material were applied to the mold during the casting. About 150 times as much material was necessary to effectuate the same chill elimination if the mold coating was applied and distributed in accordance with previously known mechanical methods. The presence of large amounts of pulverulent coating material in a mold also has a very detrimental effect on the appearance of the pipe.

21. When 200 grams of ferrosilicon, one of the pulverulent

materials used in this process, are applied to a mold for a 12-in. diameter, 18-ft. long pipe, the film of powder is only 0.0003 in. thick. Such a thin film would not cause the outside surface or dimension to change a noticeable amount.

22. When a film of ferrosilicon 0.0003 in. thick is considered as a refractory, it is found that, as such, it would be wholly inadequate to retard the heat abstraction from the molten metal a sufficient amount to prevent the formation of chill. The effectiveness of this small amount of coating, thus far is explainable only on the assumption that the particles of coating material, impelled by the carrier gas against the mold, are surrounded by an absorbed film of gas and that this film, for an appreciable time after the coating is deposited, forms an effective part of the coating and performs an important function in bringing about the absence of chill and a desirable structure in the casting.

Validates Theory

23. This assumption is based upon the results of many experiments designed to determine the cause of the results obtained by such a small amount of coating material. For instance, equally good results were obtained in one experiment where compressed nitrogen was used as a carrier gas in place of compressed air and the air inside the mold was replaced by nitrogen. Therefore, it was definitely established that the results obtained were not the result of any particular property of air.

24. It also was shown that if 200 grams of the ferrosilicon, which make it possible to cast a chill-free 12-in. diameter, 18-ft. long pipe, were added to the molten metal required to cast this pipe, the increase in silicon content would be insufficient to have any effect whatsoever upon its chilling properties. Such an addition would increase the silicon content from 1.80 to 1.82 per cent, and it is known that variations in silicon content from 1.60 to 2.20 per cent, have very little effect upon the chilling properties of the metal. The foregoing observation presupposed that the pulverulent material combined chemically with the molten iron. That this is far from the truth, is demonstrated by the fact that it can be brushed from both the outside of the castings and the inside of the mold, unaffected in composition and in noticeable amount.

25. These facts, the well known refractory property of a gas film and observations such as the necessity of applying the coating

material at a certain position in the mold just ahead of the iron stream, as shown in Fig. 8, led to the previously expressed assumption which will be investigated further in the future.

26. It already has been explained that the mold coating equipment does not interfere in any way with the normal operation of the deLavaud casting machine. It can also be said that the mold coating material itself does not interfere with the operation for, although it retards the heat abstraction from the molten metal, the difference in the time required for the metal to cool to 1500 degrees Fahr., the temperature at which the pipe is extracted,

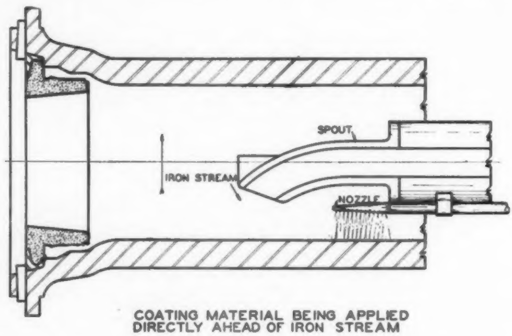

FIG. 8—DIAGRAM SHOWING HOW THE COATING IS APPLIED IN ADVANCE OF THE IRON STREAM.

has not been altered appreciably. As a matter of fact, whether or not a pipe contains chill or is chill-free is a matter of split seconds as it cools from its molten state.

27. It has been found that a number of pulverulent materials can be used effectively to prevent the formation of chill in the outside portion of the pipe wall, and it has also been found that certain materials, which will effectively eliminate chill, will not produce good outside surfaces.

28. Before passing from the method of producing chill-free or gray iron castings in a steel deLavaud mold, it should be emphasized that this was accomplished without changing the analysis of the iron used. A typical analysis of the cast iron is as follows and no so-called graphitizing elements are used nor are they desirable:

Silicon, per cent	Sulphur, per cent	Manganese, per cent	Phosphorus, per cent	Total Carbon, per cent
1.80	0.075	0.45	0.85	3.65

29. The results of physical tests made on pipes cast experimentally have shown that even considerable deviation from the foregoing analysis, as far as silicon, phosphorus and total carbon content are concerned, does not affect the quality of the pipe as much as does the lack of uniformity in cupola operation. To insure uniformity of both analysis and temperature, forehearths have been installed at all of the super deLavaud units. One type of forehearth, as shown in Fig. 9, consists of a refractory lined reservoir capable of holding approximately 12 tons of molten metal. It serves as a mixing ladle in which variations in the speed

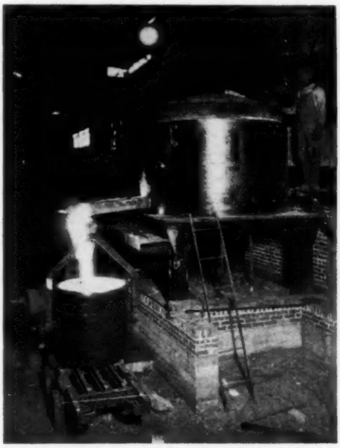

FIG. 9—TYPICAL FOUNDRY FOREHEARTH.

of melting, iron composition and temperature are reduced to a minimum.

30. The production of chill-free castings in water-cooled steel molds is an interesting subject in itself, but the superior quality of the castings, so produced, is still more interesting to both the manufacturer and the consumer. To show the excellence of super deLavaud pipe, its physical properties will be compared with the physical properties of standard deLavaud pipe cast directly against the metal mold.

31. In considering the physical properties of super deLavaud pipe, let us first consider its properties as it leaves the mold of the casting machine, for it is in the mold of the casting machine that

the fundamental metallurgical change in deLavaud pipe has been made. Fig. 10, showing the fractures of 6-in. standard and super deLavaud pipe in their "as-cast" state, makes the foregoing statement evident. It can be seen that standard pipe has a chill approximately halfway through its wall thickness. Its outside Shore hardness is 70 and in this state it is unmachineable, very brittle and quite unserviceable as a pipe. The super deLavaud fracture shows it to be a gray iron casting throughout. It contains only those constituents that are found in ordinary sand-molded castings and it has an outside Shore hardness of 30. Unlike standard

FIG. 10—FRACTURES OF 6-IN. DIAMETER CAST IRON PIPE MADE (TOP) WITHOUT MOLD COATING AND (BELOW) WITH MOLD COATING.

deLavaud pipe, it is readily machineable and has sufficient impact resistance to be serviceable pipe.

32. After standard and super deLavaud pipe are annealed by the standard practice of heating to a maximum temperature of 1700 degrees Fahr. and cooling slowly to 1200 degrees Fahr. in approximately one hour, they both are gray iron castings, having approximately the same hardness throughout their wall thickness. Since annealed standard and super deLavaud pipe have approximately the same hardness throughout, due to the reduction of the combined carbon in each to approximately 0.10 per cent and since they both are cast from metal having the same chemical analysis, a large difference in their physical properties does not seem possible, until the structures are examined under the microscope. Here it is found that, although they are constitutionally the same, their constituents form decidedly different structures, and it will

be shown later that these structures have decidedly different physical properties.

33. Fig. 11 shows microphotographs taken from the outside, middle and inside of 8-in. standard and super deLavaud pipe, magnified 100 diameters. It can be seen that standard pipe has three separate and distinct structures; an outside structure which was chilled and has been reduced to balls of temper carbon in a ferrite matrix, a middle directional dendritic structure which is normal

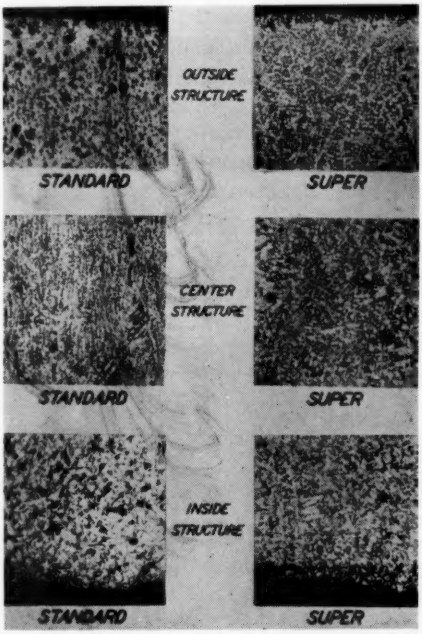

FIG. 11—MICROSTRUCTURES (REDUCED FROM ORIGINAL SIZE) OF CAST IRON PIPE MADE WITH AND WITHOUT MOLD COATING.

to the outside surface, and an inside graphitic structure which is composed of graphite flakes in a ferrite matrix. Super deLavaud pipe has but two distinct structures: a non-directional interlacing dendritic structure, and an extremely fine graphitic structure at the middle and inside of the pipe wall.

34. Dendrites are formed at a rate of cooling slightly less than that which will cause chill and at a rate of cooling slightly

greater than that which will cause a graphitic structure to form. Therefore, when the heat abstraction was retarded by the film of coating material on the mold, this structure was moved to the outside of super deLavaud pipe and, in doing so, it became non-directional. When large amounts of mold coating material are applied, as they were in previously known methods, this unique non-directional structure is not obtained, due to the excessive retardation in cooling the metal from its molten state. It is evident that such a non-directional structure would be very much tougher and resistant to a force that would rupture it, due to its interlacing nature, than would a directional structure in which planes of weakness are uninterrupted.

35. This description of the structures of standard and super deLavaud pipe is inadequate, but it will have served its purpose if it has demonstrated that, structurally, there is sufficient difference in standard and super deLavaud pipe to explain the physical test results reported subsequently. To see the real differences between these two structures, it is necessary to study a panoramic view of the entire wall thickness.

IMPACT RESISTANCE

36. The impact resistance of a cast iron pipe is a most comprehensive and reliable indicator of its quality, for impact resistance cannot be obtained without both strength and ductility.

37. The full length impact test machine, shown in Fig. 12, has been used for a number of years in determining the impact resistance of all kinds of pipe. This impact test, or a modification of it, is widely used by cast iron pipe technicians and has proved to be an excellent indicator of the resistance of cast iron pipe to shocks received in transportation, handling and in actual service. The pipe to be tested, while under an internal hydrostatic pressure of 65 lb. per sq. in , is submitted to blows from a 50-lb. hammer. The initial blow for a 6-in. diameter pipe is from a height of 6 in. and succeeding blows are from heights increased by increments of 2-in. The pipe is held firmly in 24-in. supports and the blows are all struck at the same point. The number and height of the blows are increased until the pipe fails. The height at which the first crack and first leak appear is also noted and recorded. Three points on a 12-ft. pipe can be tested in this way since the failures produced do not leak sufficiently to prevent the water pressure being maintained.

Table 1

FULL LENGTH IMPACT TEST* ON 6-IN. STANDARD AND CHILL-FREE deLAVAUD PIPE

Pipe	Average Height of Hammer in Feet at Crack	Leak	Failure
Standard Unannealed	0.94	0.94	1.16
Standard Annealed at 1700 Deg. F.	1.66	1.66	1.83
Chill-Free Unannealed	1.39	1.78	1.88
Chill-Free Annealed at 1700 Deg. F.	2.05	2.72	3.94

* Water pressure 65-lb. Initial height of hammer 0.5 ft., 2-in. increments.

38. Table 1 is a tabulation of full-length impact test results on 6-in. diameter standard and super deLavaud pipe, unannealed and annealed at 1700 degrees Fahr. These results are typical of the findings in many tests. It can be seen that annealing increases the failure height of standard pipe from 1.16 to 1.83 ft., which is approximately the failure height of super deLavaud pipe unannealed. Annealing super deLavaud pipe increases its failure height from 1.88 to 3.94-ft. In other words, annealed super deLavaud pipe has an impact resistance more than twice that of

FIG. 12—FULL-LENGTH IMPACT TESTING MACHINE.

standard deLavaud pipe annealed. These super deLavaud and standard deLavaud pipes had the same chemical analysis and, after annealing, their combined carbons were the same.

39. The same excellent impact resistance of super deLavaud pipe was also shown by full-length impact tests on 8-in. diameter pipe. Eight-in. diameter pipes are tested in the same manner as 6-in. diameter pipes except for the fact that the initial drop of the hammer is made from a height of one foot rather than 6 inches.

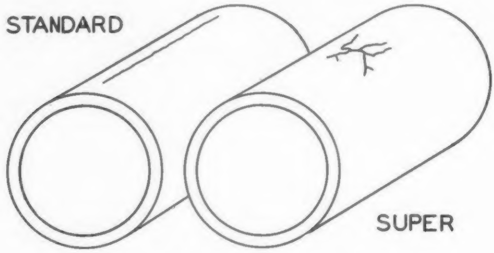

FIG. 13—TYPICAL IMPACT FAILURES.

Typical tests on annealed pipe show standard pipe failing at a hammer height of 2.88 ft. while super deLavaud pipe did not fail until the hammer was dropped three times from its maximum height of 5 ft.

40. Full-length impact tests not only showed that chill-free deLavaud pipe has exceptional impact resistance, but also that it has characteristics which are very different from Standard deLavaud pipe. Fig. 13 shows the types of failure cracks which were obtained in this test. It will be noted that the standard deLavaud failure is a single longitudinal crack which opened up soon after the leak occurred, while the super deLavaud failure consists of a number of short, tight non-directional cracks which can only be produced by actually indenting the pipe wall by a great deal of pounding after a leak occurs. These types of failure are in accordance with the directional and non-directional structures shown in the microphotographs.

41. The foregoing test results have demonstrated the fact that super deLavaud pipe is more resistant to handling shocks than standard deLavaud pipe. As has been stated previously, this improvement is the result of high strength combined with ductility, as shown by the stress-strain diagrams in Fig. 14. These

stress-strain diagrams show the stress in lb. per sq. in and the strain in in. per in., up to the point of failure of 0.505-in. diameter tensile specimens, taken from the wall of 12-in. diameter pipe. Super deLavaud metal is shown to have 62 per cent greater elongation and, at the same time, its tensile strength of 32,000 lb. per sq. in. is equal to the tensile strength of standard deLavaud metal. Bursting pressure tests also reveal the same high tensile resistance as in the standard deLavaud pipe.

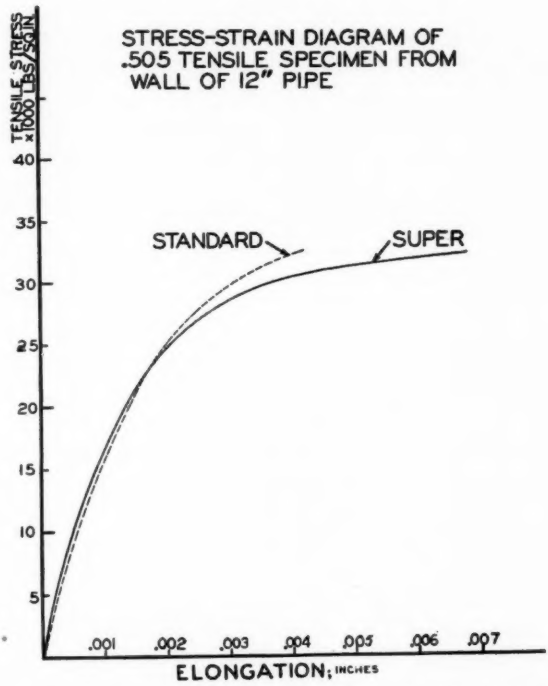

FIG. 14—STRESS-STRAIN DIAGRAM OF A 0.505-IN. DIAMETER TENSILE TEST SPECIMEN TAKEN FROM THE WALL OF A 12-IN. DIAMETER PIPE.

(*Discussion on this paper begins on page 479*)

Slush Pump Piston Cores Produced By Centrifugal Casting Process

By A. E. Falk,* Torrance, Calif.

Abstract

In this paper the author discusses the various factors and production problems involved in the centrifugal casting of a special type casting. The design of the molding equipment and foundry layout is such that a continuous system is employed, using an electric furnace for melting. The most difficult problem was the development of the mold. Steel for the material was first used, but the final selection was alloy iron, two compositions giving satisfaction, the first containing about 4 per cent silicon and the second nickel and molybdenum. All molds are cast in permanent molds and heat treated. When first used, they are for the smaller sized castings and when they fire check, they are rebored to give the next larger size casting. A satisfactory mold wash was developed, consisting of a diluted refractory cement, core oil and graphite. The foundry produces from 110 to 130 castings per day.

1. For the past four years, the company with which the writer is connected has had in successful operation a small gray iron foundry in which 90 per cent of the castings are centrifugally cast. These castings are cores for a rubber piston used in slush pumps.

2. The tremendous loads carried by these cores in service caused many formerly purchased from outside sources to crack and allow the piston to become loose on the rod To overcome these difficulties, the firm decided to install its own foundry, using an electric furnace to produce a high strength iron, and spinning the cores to produce a finer grained iron. This meant the development of the centrifugal device itself, of suitable molds, with correct spinning speed and a satisfactory core pin.

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* D. & M. Machine Works.

Note: This paper was presented at the Cast Iron session devoted to the Centrifugal Casting Symposium at the 1935 Convention of A.F.A. in Toronto, Canada.

3. The centrifugal device is set in a pit and consists of two bowls mounted on opposite ends of a pivoted frame. Over one end of the pit is a platform supporting the ladle and pouring spout; on the other end, a man is stationed to change molds with the aid of two air hoists. One hoist lowers an empty mold into the bowl. This bowl is then placed in pouring position by revolving the pivoted frame through an 180 degree arc. This places a filled mold in front of the operator.

4. The filled mold is taken from the bowl with the second air hoist, and an empty mold is again lowered into the bowl with the first hoist. This change is made while the spinning mold on the opposite end of the frame is being poured. As soon as this mold is filled, the frame is again indexed through an 180 degree arc and the process repeated.

5. The bowl with its mold is brought up to 600 revolutions per minute when starting to pour. Higher spinning speeds were formerly used, but it was found that lowering the speed gave better mold life.

6. New molds are brought into position to be handled by the hoist and filled molds taken away by small cars running on an oval track which crosses the center of the pit. Using the two bowls, changing the molds in one while the mold in the other is being poured, 12 to 15 castings can be poured in 4 to 5 minutes.

7. The filled molds are allowed to stand from 3 to 5 minutes, to allow the metal to set, before being sent to the stripping machine where the mold is pulled apart and the casting removed. The total time, from the pouring of the first casting until the last casting is in the annealing oven, will average about 15 minutes. Fig. 1 shows the general layout.

Development of the Molds

8. Perhaps the most difficult problem involved was the development of the mold. In the first molds, the casting was poured in a vertical position. This was soon given up as it was hard to hold the core in position and machine costs on the molds were prohibitive. Molds were then made in which the casting was poured in a horizontal position. This method cut machine costs and produced a casting with an extremely close grained iron in the hub, where the strength is needed.

9. Molds are now cast in two halves, a male and a female, and then machined to the size casting desired. The halves of the

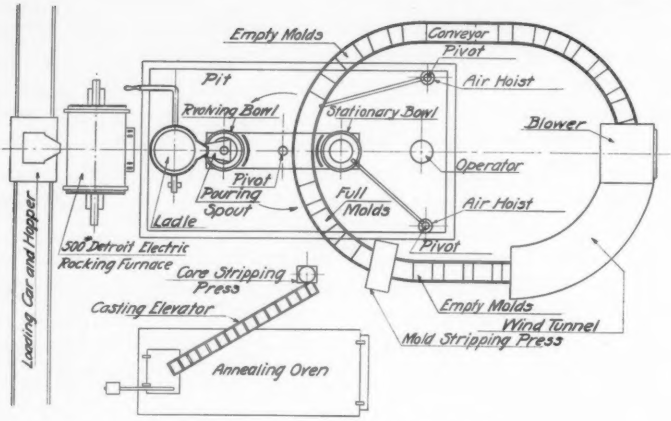

FIG. 1—GENERAL LAYOUT OF FOUNDRY.

mold, the core pin and a casting are shown in Figs. 2 and 3. The outsides of the molds are finished with a taper which corresponds to a taper in the bowls. This wedges the halves together and holds the mold in the bowl while spinning.

10. The first molds were made of steel. Although they gave fair results, their tendency to burn in and warp made their upkeep

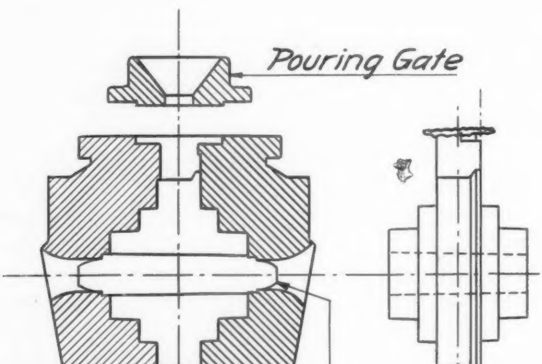

FIG. 2—CROSS SECTION OF MOLD AND SKETCH OF CASTING.

cost prohibitive. Various steel alloys were used, but the results were about the same.

11. Cast iron molds were then tried and found to be much more satisfactory. Machining costs were cut materially and they did not warp, but a new difficulty appeared. The molds fire checked. To overcome this the molds were machined out and new linings threaded in. This gave fair results, but the linings soon came loose and the molds had to again be relined. The number of castings produced on each lining was too low for the cost involved.

12. Alloy irons then were tried and found to give much better results. Many alloy irons have been tried but only two have given satisfactory results. The first of these contained 3.50

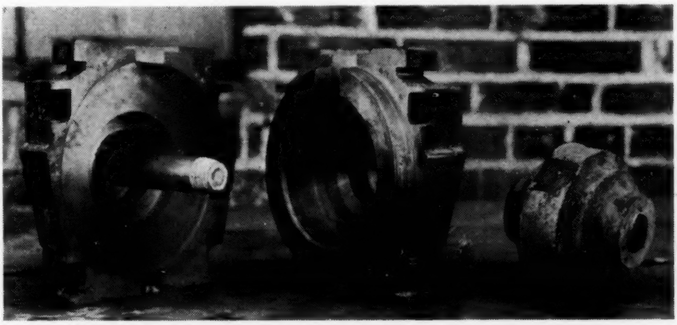

FIG. 3—PHOTOGRAPH OF TWO HALVES OF THE MOLD SHOWING CORE PINS. A CASTING IS SHOWN AT THE RIGHT.

per cent carbon, 3.90 per cent silicon, and 0.80 per cent manganese. The second had a composition of 3.20 per cent total carbon, 2.30 per cent silicon, 3.50 per cent nickel, and 0.50 per cent molybdenum.

13. The first iron is made of straight pig iron with silicon raised 1 per cent. The second is made of iron as used in production of cores with the addition of nickel and molybdenum. The addition of molybdenum has been found to decrease the fire checking but will cause a mold to crack unless heat treated so as to relieve all strains.

14. All molds are cast in a permanent mold and annealed to facilitate machining. This permanent mold is always set up and as the end of the day's run draws near, any extra iron is used for molds, the nickel and molybdenum being added as ladle addi-

tions. Their ease of casting and machining makes them by far the cheapest to use.

15. The molds are all annealed at 1700 degs. Fahr. for 2 hours and then left to cool in the oven. After machining and just before placing in service, the molds are again heated to a dull red.

16. All new molds are placed on the end of the string so as to receive the coldest iron. After 5 or 6 heats they are placed in their proper position according to size. The smallest castings are poured first.

17. All new molds are started on the small sizes and as they fire check they are rebored to the next larger size. Casting sizes vary from 6 to 8½ inches. Mold life varies from 400 to 700 castings, depending on type and size of castings needed. After each rebore the molds must again be heated to a dull red and started as a new mold.

18. The critical point in the life of a mold seems to be in the first few castings poured. Unless all strains are relieved and the mold hot, the first castings are apt to crack it. After a mold is started, it will very seldom crack and needs no attention except a spray of wash every 2 or 3 heats. Raising the total carbon will eliminate this tendency to crack to some extent, but it makes the metal softer and this increases the tendency for the mold to flake off at the point where the stream of metal first strikes the revolving mold.

COOLING MOLDS

19. After pouring a heat, all molds were formerly cooled with a spray of water. This practice proved to be too much of a shock to the hot molds and caused too much cracking and warping. The molds are now cooled slightly by passing through an air tunnel. It has been found that the molds give much better service if kept hot.

POURING THE CASTINGS

20. In pouring, the mold is started spinning at the same time the stream of metal starts. Formerly the mold was brought up to speed before starting to pour. This caused the first metal to hit the face of the mold with great force, causing flaking off of the mold and fire checking at the points where the metal first struck the mold. In starting to pour at a slow speed, this shock is eliminated and by the time the mold is up to speed a skin of

metal has formed over the face of the mold. As the mold fills the metal stream is tapered off.

21. When filled, the mold is allowed to spin a few seconds, during which time the metal can be observed to be sinking. This hollow is then filled up. On an $8\frac{1}{2}$ inch casting weighing 48 lbs., a gate approximately $1\frac{5}{8} \times 1\frac{1}{2} \times 1$ inch high is used. Due to the spinning, this casting can be made without any sign of a shrink.

MOLD WASH

22. The development of a wash was another problem. Many types of prepared washes were used but none would stick. Smoking with an acetylene flame was the practice used for a while. However, when the molds were smoked, there was a tendency for the smaller castings to have bubble holes on the face of the hub. It was decided that the metal in flying out against the soot covered mold had a tendency to splash or bubble. The smoking was discontinued and the holes in the castings disappeared.

23. A wash has now been developed that protects the face of the mold and at the same time promotes easy stripping. It consists of a diluted refractory cement, core oil and graphite.

USE OF METAL CORE PINS

24. During the pouring and spinning of the casting, the metal falls directly on the core until the mold is nearly filled. Originally sand cores were used, but invariably they would wash and burn in. To eliminate this difficulty it was decided to use metal cores. Steel was tried for this purpose, but proved a failure; the pins either burned in or, due to the higher expansion rate, cracked the hub of the castings.

25. Iron core pins eliminated cracking but not the burning in. A high chromium iron gave fair results, but machining costs were prohibitive. Finally, a high nickel iron was developed that solved the problem. This austenitic iron is of low thermal conductivity and hence absorbs heat slowly and by the time the pin has reached the temperature of the iron, the metal has already set. Very few pins have burned in since this metal has been in use, and if the pins are not stripped too hot, leave a very smooth hole.

26. The analysis of the core pins now in use is as follows:

Total Carbon, per cent	3.20
Silicon, per cent	1.50
Nickel, per cent	32.00 to 36.00
Chromium, per cent	2.50
Manganese, per cent	.80

27. The use of metal core pins developed another source of trouble. After one or two castings, the pins gave off a gas. This was traced to an oxide film on the pin. Sandblasting after each heat remedied that trouble. The pins are cleaned while still fairly hot and dipped in the same wash that is used on the face of the molds. Each pin can be used approximately 20 times before it loses its shape and has to be discarded.

CASTINGS PRODUCED

28. At the present time the foundry is producing from 110 to 130 cores per day, 5 days a week, with very little trouble. The scrap loss is very low.

29. The centrifugally cast casting has a very smooth outside surface and can be cast nearly to size, only 1/8 in. being allowed for finish. The same casting poured in stationary molds is not as smooth, corners are not as sharp, show a coarser grain structure and on machining numerous bubbles will be uncovered on the upper side.

30. Although no physical comparisons have been made between castings made in sand and castings now produced centrifugally, field tests have shown the superiority of the centrifugal casting. In deep well drilling where the old type core failed, the castings now produced are successful.

(Discussion of this paper begins on page 479)

CENTRIFUGAL CASTING SYMPOSIUM—3

The Centrifugal Casting Process with Special Reference to the Production of Engine Cylinder Liners

BY J. E. HURST,* LICHFIELD, STAFFORDSHIRE, ENGLAND.

Abstract

In this paper, the author describes in general the types of casting machines in use in the company with which he is associated and also the melting and charging equipment used as well as control of the cupola mixtures. He explains the two methods of cylinder block construction used to facilitate the use of centrifugally cast liners, namely the "wet liner" and the "dry liner" methods. The author then explains the properties and advantages of centrifugally cast cylinder liners, the importance of heat treatment and its effect on the physical properties and finally gives several compositions used in the manufacture of low alloy iron, centrifugally-cast, cylinder liners. The use of austenitic irons for centrifugally-cast cylinder liners also is discussed.

1. The centrifugal casting process has been developed extensively in Great Britain for the production of cylindrical cast iron castings such as cylinder liners, sleeve valve liners, piston valve liners and other similar cylindrical castings required for high duty purposes. The application of this process for this purpose was originated in this country and it is probably true to say that it has been developed more extensively in this country than any other. The development of this aspect of the centrifugal casting process was referred to briefly in a previous paper[1] given by the author before the A. F. A. in September 1926. This contribution will be confined more largely to the production of engine cylinder liners.

2. The essential features involved in the centrifugal casting process are now well understood and it is sufficient to say that in the plant with which the author is associated, the cylinder liner castings are produced by casting into rotating metal molds. The molds are made of cast iron and, in general, normal, atmospheric

NOTE: This paper was presented at the Centrifugal Castings Symposium at the 1935 Convention of A.F.A., Toronto, Canada.

* Technical Director, Sheepbridge Stokes, Centrifugal Castings Co., Ltd., Chesterfield and Bradby & Foster, Ltd., Darleston, England, President, Institute of British Foundrymen.

[1] *Some Notes on the Development of The Centrifugal Casting Process in Great Britain and Europe*, TRANSACTIONS A.F.A., Vol. 34 (1926) pp. 163-176.

cooling is relied upon. Regularity of mold temperature for a given size of mold is ensured by strict control of the rate of casting. A view taken recently in the centrifugal casting foundry is shown in Fig. 1. Illustrations of the smaller type of machine for the production of castings within the range of automobile engine sizes and larger castings up to about 30 inches diameter are shown in Figs. 2 and 3.

FIG. 1—CENTRIFUGAL CASTING FOUNDRY OF SHEEPBRIDGE STOKES CENTRIFUGAL CASTINGS CO., LTD., ENGLAND.

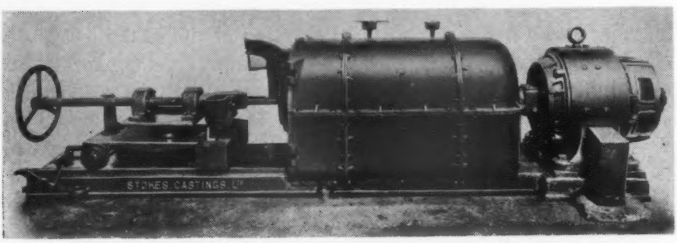

FIG. 2—A SMALL TYPE CENTRIFUGAL CASTING MACHINE.

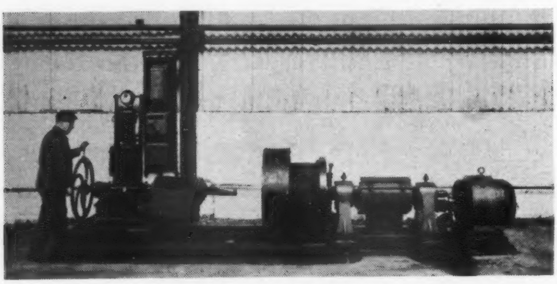

FIG. 3—INTERMEDIATE TYPE CENTRIFUGAL CASTING MACHINE FOR CASTINGS UP TO 30 INCHES IN DIAMETER.

3. The plant of the company has been extended largely to cope with the developments in the application of centrifugal castings to the production of cylinder liners and valve seat inserts for motor car and commercial vehicle engines. The research laboratories are responsible for the development of alloy cast irons suitable for nitrogen hardening, hardening and tempering and have also played a very important part in the development of austenitic cast irons suitable for heat and corrosion resistance.

MELTING EQUIPMENT

4. Melting arrangements are a most important feature of the plant. They are specially designed to provide molten metal to very strictly guarded limits of accuracy in chemical composition and uniformity of physical and mechanical properties. The cupola plant consists of four cupolas, having a melting rate of 2 tons per hour each. Two of the cupolas are equipped with the Poumay system of auxiliary tuyeres, and charged by an inclined hoist and bucket system of mechanical charger. The other two cupolas are equipped with ground-controlled monorail bucket charging. The entire charging of these cupolas is operated and controlled from the ground level.

5. Incoming materials are carefully controlled by the laboratory. Each consignment of pig iron is stacked and painted according to its brand and truck number, and is only released for use after the composition has been checked carefully by the laboratory. Even with the most careful control of the cupola mixture, the components of which are different in character, it has been found impossible to eliminate slight irregularities in composition due to the irregular settlement of the burden in the cupola. These irregularities are of sufficient magnitude to affect the properties of the material for cylinder liners. With the object of ensuring that the molten metal supplied to the casting machines shall be free from such variations, a large oil-fired receiver is installed. This receiver is of 2-tons capacity and is operated by crude oil and pressure air supplied by a centrifugal fan. The molten metal is transferred as melted from the cupola to this receiver, where it can be stored and maintained hot for delivery to the casting machines as and when required. In addition to its effect in smoothing out possible irregularities in composition, the receiver makes a constant supply of molten metal at a uniform temperature available for the casting machines. An illustration of this receiver is shown in Fig. 4.

6. In addition to the melting plant for cast iron, the works are equipped with pit-fired crucible steel melting holes for melting steel, monel metal, and other non-ferrous alloys, oil-fired tilting crucible furnaces, and a battery of rotary oil fired furnaces.

Cylinder Liners

7. The excellent mechanical and wear resisting properties of centrifugally-cast material are taken advantage of in the production of liners. The obvious disadvantage in the ordinary monobloc cylinder construction is that its complexity and difficulty as a casting problem render the question of the suitability of the mate-

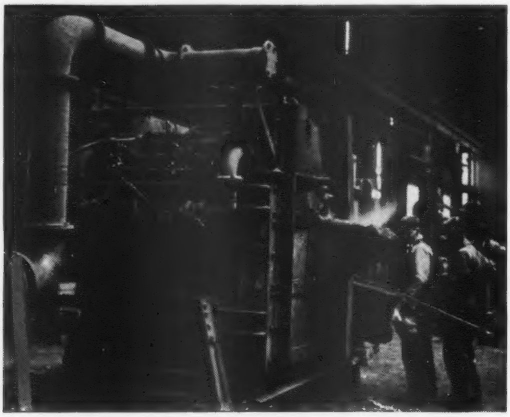

FIG. 4—OIL-FIRED, TILTING, RECEIVER.

rial to withstand the wearing conditions of modern practice a secondary consideration. The more strenuous demands of modern automobile engine construction, brought about by such considerations as increased piston speed, the use of aluminum alloy pistons, particularly in commercial vehicles, has led designers to reconsider the question of cylinder design in which the cylinder bore can be made more definitely wear resisting.

8. Two alternative methods of construction present themselves. One, known as the "wet liner" method, in which the cylinder barrels are constructed separately and inserted into a more or less simple form of outer casing or water jacket. The alternative method utilizes the existing type of monobloc cylinder casting into the cylinder bores of which thin liners are pressed. This is

known as the "dry liner" method. The "dry liner" is a cylinder approximately 1/16 in. thick and has a small flange on one end. The outside of the liner is ground to close limits, but the bore is left with an allowance for grinding after fitting.

9. The cylinder itself is bored a few thousandths of an inch smaller than the liner, so that there is an interference fit between the cylinder and the outside of the liner when the latter is pressed in, thus providing a tight fit. A recess is also machined at the upper or lower end of the cylinder (depending on whether the head is detachable or fixed) to accommodate the flange on the liner, and to ensure that there is no movement. When finally in position, the liner is accurately ground to the correct size.

CYLINDER LINER MATERIAL.

10. Cylinder liners are manufactured to a number of different specifications, the choice of which is determined by the nature of the operating conditions. In many cases, economic considerations are a prime factor and the standard material used is a plain chromium alloy cast iron complying with the general requirements of the British Standard Specification for Aircraft Material 4K6 and containing an addition of chromium up to 0.4 per cent. Testing methods used are all based upon the ring test described in this specification and no difficulty is experienced in conforming to the limits laid down.

11. A comparison of the ultimate breaking strength properties does not bring out so clearly the difference in physical characteristics between centrifugal castings and castings produced by other methods as does a comparison of certain other attributes of the strength properties. For example, Figs. 5 and 6 show the range of variation in modulus of elasticity and permanent set for a number of specimens of different materials. These results reveal a clearly marked difference in these properties, the centrifugal cast material having a substantially higher modulus of elasticity (and a lower permanent set value. The modulus of elasticity is that referred to as EN value in the specification above mentioned). In other words, these differences indicate a higher degree of stiffness, rigidity and resistance to deformation in the centrifugal castings and those familiar with the nature of cylinder wear will agree that such properties cannot be overlooked in cylinder wear considerations.

12. An important influence of heat treatment by oil-hardening and tempering, in addition to its influence in increasing the

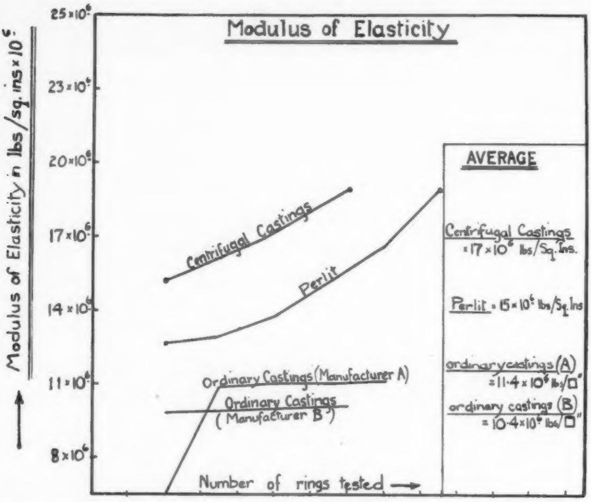

FIG. 5—AVERAGE RESULTS OF TESTS TO DETERMINE THE MODULUS OF ELASTICITY OF PISTON RING MATERIAL.

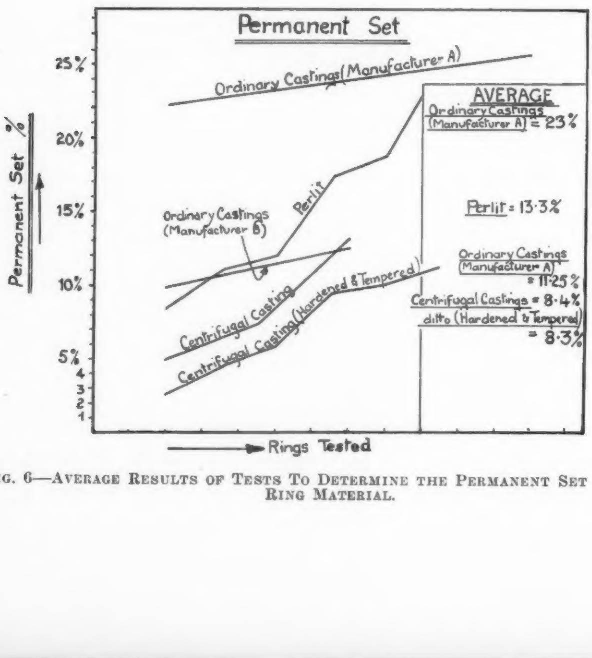

FIG. 6—AVERAGE RESULTS OF TESTS TO DETERMINE THE PERMANENT SET OF PISTON RING MATERIAL.

hardness value, lies in its influence in lowering the permanent set value. Hardened and tempered cast irons are consistently lower in permanent set value than the same material in the "as cast" untreated condition. The effect of hardening and tempering treatment on the permanent set value after various hardening and tempering treatments, are recorded in Table 1.

Table 1

EFFECT OF HEAT TREATMENT ON THE PERMANENT SET VALUE.

Spec. No.	Treatment.	Percentage Permanent Set after quenching in oil from:— 920° C.	860° C.	830° C.	800° C.
1.	As cast	7.95	7.95	7.95	7.95
2.	Quenched in oil	—	4.35	6.2	4.2
3.	Tempered at 200° C. (392° F.)	—	2.86	2.86	—
4.	Tempered at 250° C. (482° F.)	1.50	2.74	2.82	1.45
5.	Tempered at 300° C. (572° F.)	1.52	2.9	1.64	1.43
6.	Tempered at 350° C. (662° F.)	1.67	1.51	1.50	1.50
7.	Tempered at 400° C. (752° F.)	—	0.62	2.78	—

13. The standard chromium alloy material cylinder liners can be hardened and tempered and dry liners, hardened by quenching in oil from a temperature of 850 to 875 degrees Cent. (1562 to 1607 degrees Fahr.) and tempered at 350 to 375 degrees Cent. (662 to 707 degrees Fahr.), are raised to a Brinell hardness of approximately 450. For wet liners, particularly those which have a comparatively large radial wall thickness, it is preferable generally to incorporate nickel in the alloy to ensure effective penetration of the hardening effect throughout the radial thickness.

14. A further important alloy cast iron specification used for the manufacture of cylinder liners is the molybdenum-chromium alloy cast iron. The composition used complies with the requirements of the specification D. T. D. 233, as follows:—

Element	Per Cent
Total Carbon	3.4 max.
Combined Carbon	0.6 min.-0.9 max.
Silicon	1.8 min.-2.4 max.
Manganese	0.7 min.-1-2 max.
Sulphur	0.08 max.
Phosphorus	0.70 max.
Molybdenum	0.60 min.-1.25 max.
Chromium	0.35 min.-1.0 max.

15. It is of interest to record that recent investigations have

revealed an important effect of molybdenum additions in the retention of high values of the elastic characteristics at moderately high temperatures in the neighborhood of 300 degrees Cent. (572 degrees Fahr.). It is highly probable that these effects of molybdenum are responsible for the excellent service behavior of molybdenum alloy irons both as cylinders and piston rings in internal combustion engines.

Austenitic Irons

16. In the range of austenitic cast irons, centrifugally cast cylinder liners are produced in specifications of the nickel-manganese, nickel-copper-chromium and nickel-silicon-chromium types, whose compositions are shown in Table 2.

Table 2

Typical Specifications of Austenitic Cast Irons

	Ni-Cu-Cr. Hypocrode.	Ni-Si-Cr. Nicrosilal.	Ni-Mn.
Total Carbon, Per Cent	3.1 max.	1.6-2.2	2.5-2.75
Silicon, Per Cent	1.3-2.0	5.0-6.0	0.75-2.0
Manganese, Per Cent	0.75-1.25	0.5-0.8	3.75
Phosphorus, Per Cent	0.5 max.	0.5 max.	0.1 max.
Nickel, Per Cent	12.5-14.5	18.0-20.0	6.5
Copper, Per Cent	4.0-6.0	—	—
Chromium, Per Cent	4.5-5.5	1.8-5.0	—

17. The service behavior of austenitic cast irons is intimately bound-up with the condition of the graphite and fine graphite appears to favor excellent service behavior. The casting of austenitic irons by the centrifugal process ensures a fine graphite structure and herein lies an important advantage of this process in its application to irons of this type. The introduction of austenitic cast irons has led to the development of temper hardening or age hardening processes to cast iron. It has been discovered that hardening of this type can be developed in certain specifications of austenitic cast iron by exposure to low temperature treatment generally in the neighborhood of 500 degrees Cent. (932 degrees Fahr.). For example, in the nickel-manganese specification, treatment at a temperature of 500 degrees Cent. (932 degrees Fahr.) will develop a Brinell hardness of over 400. This appears to be brought about by a change to the martensitic structure and may prove of value probably in the application of these irons to cylinder liner purposes.

18. In addition to the above, cylinder liners are manufac-

tured also in aluminum-chromium alloy cast irons, suitable for nitrogen hardening. These have been described fully in current technical literature.

19. It is hoped that this brief survey of this aspect of the development of the centrifugal casting process in England will prove of value.

ACKNOWLEDGMENTS

20. The author is indebted to Sheepbridge Stokes Centrifugal Castings Co. Ltd. and Stokes Castings Ltd., the builders of the casting machines, for the permission, freely given, to publish this information.

(Discussion of this paper begins on page 479)

CENTRIFUGAL CASTING SYMPOSIUM—4

The Sand Spun Centrifugal Process for Making Cast Iron Pipe

By Dr. James T. MacKenzie,* Birmingham, Ala.

Abstract

The sand-spun process of manufacture of cast iron pipe is just what its name indicates — pipe formed in sand lined molds which are spun centrifugally. The author points out the advantages of the process and explains methods employed in some detail. He points that many types of pipe may be manufactured by this process and states that the various processes used in the manufacture of this pipe are rigidly controlled and all precautions are taken to make this product one of high quality.

1. The nature of the "sand-spun" process is indicated by the name itself—that is, the pipe is cast centrifugally in a sand lined mold. The particular advantages of this process are that it combines the very important feature of slow cooling and self-annealing the pipe in sand, thus producing a true gray iron structure; with the equally important feature of the centrifugal method ot forming the pipe, which imparts high pressure to the metal while still in the fluid state, thus completely removing all slag, gas and other foreign material from the iron. Due to the difference in their respective specific gravities, these lighter particles are forced out of the metal to the inside of the pipe.

2. Pipe purchased by this process have a homogeneous metal structure free of inclusions, of uniform cross-section and high strength, thus permitting the use of pipe much lighter in weight for a given service than was formerly possible.

3. The product is marketed under the following trade names: "Mono-Cast" (American Cast Iron Pipe Co., Birmingham, Ala.), "Sand-Spun" (R. D. Wood Company, Philadelphia. Pa.), "Warren-Spun" (Warren Foundry & Pipe Corporation, Warren Pipe Company of Massachusetts, Inc., 11 Broadway, New York City).

4. The process consists of spinning and forming molten iron in a sand-lined mold for a sufficient length of time to permit the

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* Chief Chemist and Metallurgist, American Cast Iron Pipe Co.

Note: This paper was presented at the Symposium on Centrifugal Casting held at the 1935 Convention of A.F.A. in Toronto, Canada.

iron to set or "freeze" and to maintain its shape as a tube or pipe. The complete pipe is formed as a unit in approximately 5 seconds. With the molten metal in contact with the sand-lined mold, it requires from 30 minutes to 1 hour, depending upon diameter and metal thickness, for the metal to cool to a temperature where the pipe is virtually free of color and is ready to be removed from the mold. By this process of slow cooling, and annealing in sand, surface chill, hard spots, cooling stresses, etc. are avoided.

Cast in Sand-Lined Molds

5. The pipe is cast horizontally in a metal flask in which specially prepared molding sand has been previously rammed to form a mold for each pipe, the mold having the exact contour of the outside of the pipe. The inside of the bell, or the socket of the pipe, is formed by the use of a sand core which is inserted into the bell at one end of the mold. The bead on the spigot end of the pipe is formed in the sand on the opposite end of the mold. The outside diameter of the pipe is determined by the size of the metal pattern used in the ramming operation for forming the sand mold. The thickness of the pipe wall is determined by the amount of molten metal poured into the mold at the time of casting.

6. The flask, after being lined with molding sand, is placed in a horizontal spinning machine and revolved at a predetermined speed. The exact amount of molten metal required to make the pipe is poured into the revolving mold, the spinning of which is varied with the diameter of the pipe and its metal thickness. The speed must be sufficient in each case to create enough centrifugal force, acting on the molten metal, to uniformly distribute the metal throughout the entire length of the mold, and to hold the fluid metal in position on the wall of the sand-lined mold until it solidifies.

7. The force of gravity is the only pressure present to separate gas, slag, etc. out of the metal of castings made in stationary molds. But, gravity is multiplied many times by the use of the "sand-spun" centrifugal casting process. One of the primary advantages of this process of casting pipe is the fact that the metal is held in place on the sand-faced mold in a completely fluid state under high centrifugal pressure for a relatively long time, thus, all gas, slag, and other foreign materials are forced out of the iron,

due to their lighter weight, onto the inside surface of the pipe. This foreign material is removed in the regular cleaning operation.

8. After the pipe has cooled sufficiently, it is withdrawn from the mold and moves through the successive steps of inspection, cleaning, coating, testing, weighing and marking, all of which are carried on under close supervision.

9. The flask is returned to the ramming station where a new lining of molding sand is rammed into place for each pipe that is cast. There are enough flasks maintained in the cycle to permit all operations to be carried on simultaneously, thus producing a continuous operation.

10. By this process of centrifugal casting in a sand lined mold, it is practical to manufacture pipe with many different kinds of ends, such as bell and spigot pipe with bead cast on, flanged pipe, mechanical joint pipe, plain end pipe, pipe with tapping bosses cast integral, etc.

RIGID SPECIFICATIONS FOR MATERIALS

11. All material and supplies entering into the manufacture of the pipe by this process are purchased under rigid specifications and are subject to careful inspection as well as searching physical and chemical analysis. The operation of converting these raw materials into the finished product is carried out under the strictest supervision. A multiplicity of routine process, product inspections and tests are maintained, and specimens are taken from the walls of the finished pipe as a final test and check of physical properties of the product.

12. By virtue of the process of manufacture and the rigid tests and inspections which are maintained as routine during manufacture, pipe made by this process is a high grade product with excellent physical properties.

13. Pipe made by the sand-spun process has greatly expanded the field of application of cast iron pipe. It is now in extensive use at higher operating line pressures and for a variety of services thought to be impractical for cast iron pipe only a few years ago.

(Discussion of this paper begins on page 479)

SYMPOSIUM—CENTRIFUGAL CASTING
DISCUSSION

In the absence of Messrs. Hurst and Falk, their papers were presented by Dr. J. T. MacKenzie, American Cast Iron Pipe Co., Birmingham, Ala., and Max Kuniansky, Lynchburg Foundry Co., Lynchburg, Va., respectively.

DR. J. T. MACKENZIE[1]: Mr. Stuart mentioned that the thickness of the film of ferro-silicon referred to in paragraph 21 of his paper, if calculated on the area of the mold, would be 0.0003 in. I would like to know how that corresponds to the size of the largest particles? Also, could Mr. Stuart give us some idea of the distribution of sizes in the alloy they used?

MR. STUART: The 0.0003 in. film referred to is misleading. This film thickness was determined by dividing the volume of ferro-silicon used in casting a pipe, by the area of the mold. The actual film thickness, including the air, is considerably thicker than 0.0003 in., but we have no way of telling just how thick it is. We know that the outside diameter of super deLavaud pipe is practically the same as the outside diameter of standard pipe, therefore, the film cannot be very thick. As to the particle size, 95 per cent of the product passes a 150 mesh sieve, which has a screen opening of 0.0041 in.

MEMBER: Is there any minimum speed of revolution that is practiced to insure getting sound castings? I presume the speed varies with different sizes. Is there any data Dr. MacKenzie could give us on that?

DR. MACKENZIE: The paper as printed contains a table of speeds but they are very largely determined by experiment. In the shop where we start at full speed, we use less speed than in the shop where we accelerate suddenly. The ordinary speed, for instance, on 24-in. diameter pipe would be about 500 R.P.M. Whereas with a 4-in. diameter pipe, we run it up to 1300 R.P.M.; and a 3-in. diameter pipe ought to go faster than 1500 R.P.M. That is about all we can do but our loss is higher with the 3-in. than with the 4-in. diameter type.

MEMBER: Those cylinder liners mentioned in Mr. Hurst's paper would have to be run at quite high speed, would they not?

DR. MACKENZIE: No, not particularly high speed. I think generally speaking a metal mold runs slower than a sand mold.

MEMBER: For a 36-in. diameter pipe, what would be the elapsed time from the time the metal is introduced until the pipe is picked up?

DR. MACKENZIE: It depends a great deal upon the pouring temperature and the amount of iron. Actually a pipe is a pipe in about 17 minutes. We shut down the machine then.

MEMBER: In paragraph 28 of Mr. Stuart's paper, the author has given a typical analysis of the standard and super deLavaud pipe showing a total carbon of 3.65 per cent. In paragraph 32 he says, as a result of the annealing process, the combined carbon is reduced to approximately

[1] American Cast Iron Pipe Co., Birmingham, Ala.

0.10 per cent. Do I understand that the carbon analysis would show 3.55 per cent graphitic and 0.10 per cent combined carbon?

MR. STUART: Yes.

MEMBER: Is it possible to spin 1½-in. diameter pipe, 5 feet long and 3/16 in. thick?

DR. MACKENZIE: It probably is possible but it certainly would not compete with the ordinary method. As you go down in size, the time necessary for ramming and casting tends to straighten out and the tonnage drops off tremendously. While I have no doubt you could cast a 1½-in. diameter pipe, it would take a great deal more work and would be very much more expensive. The only justification for it would be in the field of high priced tubes. If anybody wanted to get a real superjob in a certain tube, it might be worth the money but for ordinary cast iron pipe, I would say "No." In Brebach, they do cast 2½-in. diameter pipe with about an 8 millimeter (0.32-in.) wall, 5 meters long.

CHAIRMAN M. KUNIANSKY[2]: In the deLavaud process, I believe one would find the size of the trough delivering the metal an obsticle, for it could not be made small enough to go into the opening for such a small diameter pipe.

MEMBER: I was particularly interested in the construction of the machine described by Dr. MacKenzie. About the drive on that, is that driven on rolling tires or is it driven directly from the motor?

DR. MACKENZIE: It is driven directly from the motor through a magnet. The magnet holds the end of the flask on the clutch plate depending upon friction to hold it. Magnetic contact and friction drive.

MEMBER: Do you calculate the centrifugal force in pounds per pound of metal? If so, approximately what does that run?

DR. MACKENZIE: We calculate it on a basis of 75 pounds per pound of metal.

MEMBER: Are there any limiting factors controlling the ratio of wall thickness to the overall diameter of pipe?

DR. MACKENZIE: We are very largely limited by available speed. When you begin to get thick walls, the spinning has to be at that rate of speed for the inside diameter. So, if you cast say, 10-in. diameter pipe with a 3-in. wall thickness, you would have to spin it at the same rate as you would for a 4-in. diameter pipe with the ordinary wall thickness, which is almost impossible with a flask that big.

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[2] Lynchburg Foundry Co., Lynchburg, Va.

X-Ray and Welding
The Foundryman's Aid to Quality Steel Castings

By C. M. Underwood[1] and E. J. Ash,[2] Washington, D. C.

Abstract

This paper reviews the assistance that x-ray studies and welding of steel castings has rendered the Naval Gun Factory. The paper discusses the routine inspection of production castings, the examination of pilot castings and the cooperative procedure followed in salvaging castings by removing the defects and welding, together with some of the problems involved. The changing of patterns to avoid tears and shrinkage areas is also discussed and illustrations are shown. Some other problems reviewed are: Welding low alloy castings susceptible to air hardening, possibilities of removing hardness by proper bead sequence, and removal of stresses produced by weld heating and contraction. A number of illustrations of methods of preparing welds for gun carriage castings are shown.

1. Radiographic examination of steel castings is a relatively new method for studying the fitness and quality of castings for service. This type of examination is unique in the sense that the quality of a casting is not only based upon the chemical and physical properties of the metal from which the casting is made and the surface appearance of the casting, but upon the soundness or continuity of the internal metal. In the final analysis, the latter factor should be the criterion for determining the fitness of castings to withstand shock and repeated stress.

2. This paper will review the assistance that X-ray and welding studies of steel castings has rendered the Naval Gun Factory in three phases of its work. These phases comprise the routine inspection of production castings, the examination of pilot castings, and the co-operative procedure followed in salvaging

[1], [2] Senior Welding Engineer and Assistant Metallurgist, respectively, Naval Gun Factory.

Note: This paper was presented at a session on Steel Founding at the 1935 Convention of A.F.A. in Toronto, Canada.

castings by removing the defects and welding; together with some of the welding problems involved.

X-RAY EQUIPMENT

3. In June 1934, the Naval Gun Factory purchased a portable X-ray machine, specially designed and built for ordnance requirements. The two salient features of this machine are its portability and flexibility. The machine is a self-contained unit,

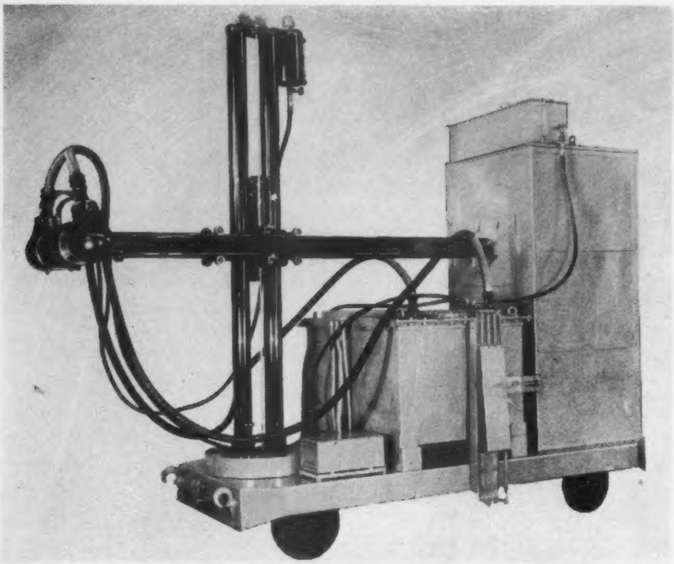

FIG. 1—PORTABLE X-RAY MACHINE WITH SHIELDED, SHOCKPROOF, ADJUSTABLE HEAD; OIL IMMERSED TRANSFORMER AND RECTIFYING UNIT, AND CONTROL CABINET.

mounted on a truck (see Fig. 1, 2 and 3) and can be moved from shop to shop or wherever its use is required. The only service necessary is a 220 volt, single phase power source. The machine has a variable voltage up to 220,000 on the secondary or tube circuit and is satisfactory for radiographing castings and welded plates up to 3½ inches in thickness.

4. The protective head, enclosing the shock-proof X-ray tube, is mounted on a stand capable of 280 degrees horizontal rotation and with the additional vertical and traversing adjustments will cover any point of an imaginary figure eight feet cube. It is thus

possible to examine a comparatively large casting by moving only the adjustable head rather than the material or the machine.

Shielding Operator

5. One of the difficulties normally encountered with X-ray operation is in shielding the operators or surrounding personnel against harmful rays. The conventional arrangement is to have

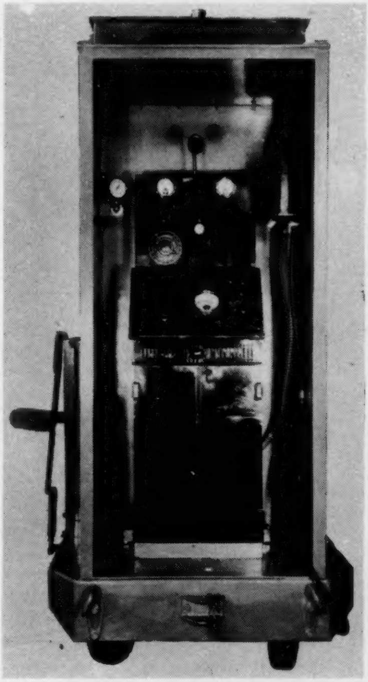

FIG. 2—CONTROL BOOTH OF PORTABLE X-RAY MACHINE. INSTRUMENT PANEL AND REGULATING SWITCHES ARE SHOWN.

a lead lined room in which the X-ray tube is located. Work must be placed on a truck or in some similar way transported into this room. In order to turn the work it must be removed from the room for accessibility to crane service. An alternative, is to have a removable roof over the lead lined chamber but this method is often equally cumbersome.

6. The expense of building a lead lined room of sufficient size to handle large castings may be excessive. This difficulty has

been effectively overcome in the Naval Gun Factory machine by enclosing the X-ray tube itself in a lead-lined casing. An aperture is provided in the casing that will permit emission of the X-rays only in a controlled direction or toward the section under examination.

7. Movable lead-lined screens are also provided about the work and small lead plates may be used as an additional protection to stop scattered or secondary radiation. This shielding arrangement has proven adequate as periodical medical examination of personnel working with the equipment has disclosed no harmful results. The small amount of lead shielding required is sufficiently flexible to permit ready handling of material with cranes about the machine.

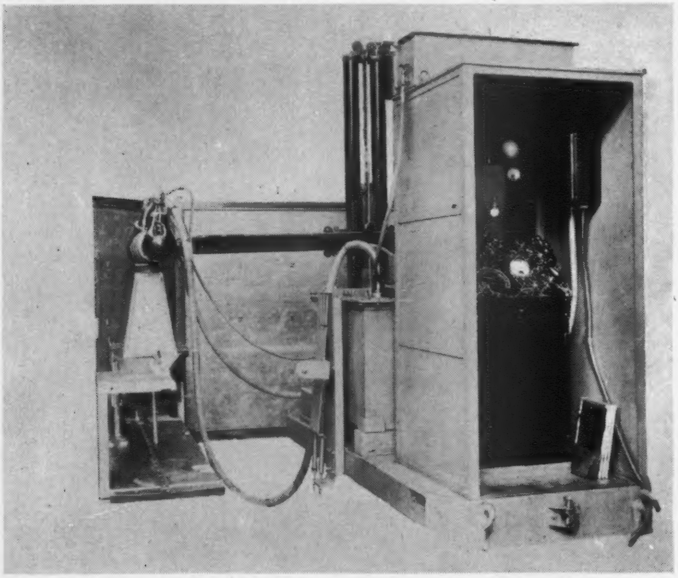

FIG. 3—RADIOGRAPHING STEEL CASTING. X-RAY HEAD IS IN POSITION OVER AREA BEING EXAMINED. SMALL LOCAL LEAD SHIELD IS PLACED BETWEEN HEAD AND CASTING. LEAD-LINED SCREENS ARE SHOWN BEHIND THE MACHINE.

8. As a further precaution the machine controls are located in a lead-lined cabinet at the rear of the machine. The X-ray tube is immersed in an oil of exceptionally high dielectric strength as are the rectifying or kenetron tubes. The machine is equipped with a pump which circulates oil through the target of the X-ray

tube during operation so excessive temperatures will not result from sustained operation.

ROUTINE INSPECTION OF CASTINGS

9. The Naval Gun Factory machine has been in daily use since its installation and for several months was operated 16 hours per day. As a result of the ability of this machine to detect internal defects and probable sources of weakness, X-ray examination of important ordnance castings is required as a routine step in production. An essential feature of this type of testing is the speed with which final results are obtained. The average procedure is to expose the film from 1 to 5 minutes and develop it in the same manner as other photographic films. The entire processes can normally be performed within twenty minutes.

EXAMINATION OF PILOT CASTINGS

10. Another practical application of the X-ray type of examination is the study of newly designed castings. The examination of pilot castings reveals any defective areas that occur and are likely to repeat in production of subsequent work. Corrective action may then be taken.

11. By varying the casting design and foundry practice to produce a sound casting, the costs of subsequent repair or total rejection, either during the machining operations or later in service, may be avoided.

12. Such analyses of pilot castings form a potent tool in the making of quality products. It is obvious that X-ray is one of the most searching non-destructive means of examination available.

Examples of Pilot Castings

13. The following examples will serve to illustrate the part that may be played by X-ray in the production of sound steel castings. Fig. 4 is a partial sketch of a 5-inch slide casting weighing about 4000 pounds. Although the outer appearance of the casting was satisfactory, radiographic examination disclosed numerous hot tears near the trunnions or cylindrical side projections.

14. The upper sections of Figs. 5, 6 and 7 are radiographs of typical defective areas that appeared sound upon the surface.

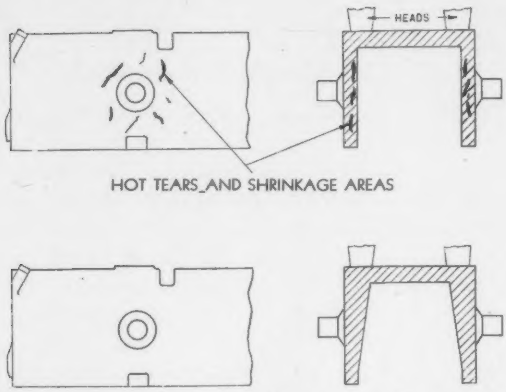

FIG. 4—SECTIONAL SKETCH OF 5-INCH 38 CALIBER SLIDE CASTING. ILLUSTRATION SHOWS LOCATION OF INTERNAL DEFECTS LOCATED BY X-RAY AND CORRECTIVE CHANGE EMPLOYED.

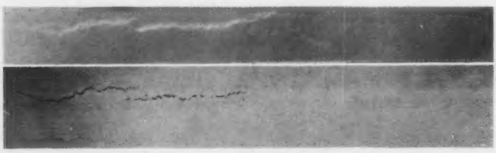

FIG. 5—UPPER SECTION RADIOGRAPH OF STEEL CASTING WHICH APPEARED PERFECT BUT CONTAINED INTERNAL TEARS AND SHRINKAGE. LOWER SECTION PHOTOGRAPH OF THE SAME AREA AFTER SUFFICIENT METAL WAS REMOVED TO DISCLOSE SOME OF THE DEFECTS.

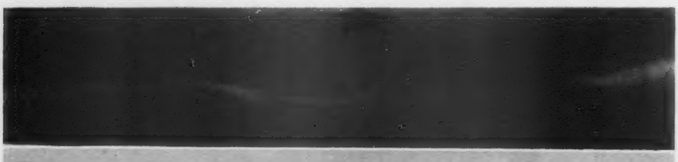

FIG. 6—UPPER SECTION RADIOGRAPH OF STEEL CASTING WHICH APPEARED PERFECT BUT CONTAINED INTERNAL TEARS AND SHRINKAGE. LOWER SECTION PHOTOGRAPH OF THE SAME AREA AFTER SUFFICIENT METAL WAS REMOVED TO DISCLOSE SOME OF THE DEFECTS.

FIG. 7—UPPER SECTION RADIOGRAPH OF STEEL CASTING WHICH APPEARED PERFECT BUT CONTAINED INTERNAL TEARS AND SHRINKAGE. LOWER SECTION PHOTOGRAPH OF THE SAME AREA AFTER SUFFICIENT METAL WAS REMOVED TO DISCLOSE SOME OF THE DEFECTS.

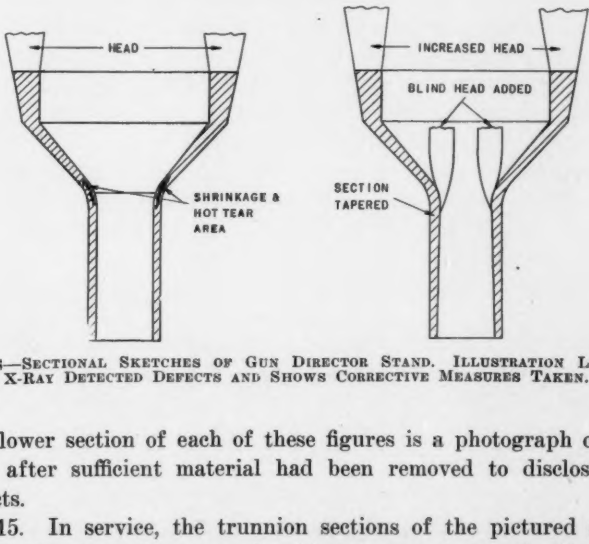

FIG. 8—SECTIONAL SKETCHES OF GUN DIRECTOR STAND. ILLUSTRATION LOCATES X-RAY DETECTED DEFECTS AND SHOWS CORRECTIVE MEASURES TAKEN.

The lower section of each of these figures is a photograph of the area after sufficient material had been removed to disclose the defects.

15. In service, the trunnion sections of the pictured slides are highly stressed areas and subject to repeated load. Some of the defects observed were of a nature subject to propagation and were therefore undesirable. A cross-section of the original design

is shown in the upper part of Fig. 4. It will be observed that the vertical walls are of equal section.

16. The hot tears and shrinkage defects occurring in the original design were eliminated by tapering the sidewalls as indicated in the lower sketch of Fig. 4. This is a simple illustration of directional solidification.

17. A similar case is a gun director stand casting weighing approximately 1200 pounds, sketched in Fig. 8. Radiographic examination showed shrinkage defects in the region indicated. In addition to the tapered section as pointed out above, it was further necessary to place blind risers as illustrated. This practice eliminated the defects from the areas in question. Thus by radiographic examination it is possible to produce castings of known soundness, minimizing the chance of having internal defects subsequently appear.

Previous Welding Limitations

18. Welding has formerly been used to a limited extent in repairing quality steel castings. Minor surface repairs have been permitted where stress of low magnitude were involved and a satisfactory finish was essential. Some form of electric arc welding has generally been employed for the most economical results.

19. For a number of years carbon arc welding was used extensively but deposition by this method is usually lacking in the desirable physical characteristics. Metallic arc welding with bare electrodes has been used more recently. Depositions with this material produce physical properties ranging from 55,000 to 60,000 lbs. per sq. in. tensile strength but having only 2 to 8 per cent elongation, with fatigue and impact properties proportionately poor.

20. Until such time as better welding materials became generally available, the application of casting repair by welding was obviously limited. During the past several years, however, a very satisfactory type of mild steel, covered welding electrode has been developed.

Properties of Deposited Material

21. Covered electrodes are now used extensively for numerous forms of fabrication. The properties of the deposited material acceptable for naval use range from 60,000 to 70,000 lbs. per sq. in. tensile strength, 45,000 to 55,000 lbs. per sq. in. yield

point, 20 to 30 per cent elongation in 2 inches, 60 to 75 ft. lbs. Izod impact values, 26,000 to 30,000 lbs. per sq. in. endurance limit and other physical properties proportionately satisfactory.

22. To keep pace with the rapid advancement and more general use of alloy steels, numerous types of covered, alloyed rods have also been developed. More outstanding among these are the ferrous alloys of manganese, nickel, molybdenum, nickel-copper and manganese-vanadium.

23. The alloying elements in weld deposits are obtained by using an alloy steel core, by pick-up through chemical reaction with the covering or by a combination of the two methods. Tensile strengths ranging from 80,000 to 110,000 lbs. per sq. in., with elongations varying from 25 to 15 per cent are obtainable.

24. The alloy rods as yet have not had the extensive application of mild steel electrodes but some of them appear particularly promising and may prove entirely satisfactory for application where higher physical properties or homogeneity of repaired section are essential.

Welding Procedure Applied to Casting Repair

25. Mild steel in its various rolled forms is now extensively fabricated by the use of arc welding. When similar welding procedures are applied to steel casting repair, however, unsatisfactory results are often obtained. Casting repair involves a number of peculiarities which must be taken into consideration.

26. Many steel castings are of a chemical composition not ordinarily suited for welding. Alloying elements, such as carbon, chromium, nickel, manganese and silicon are common hardening elements which are affected by welding temperatures. Carbon being the most potent alloying element, should be kept within satisfactorily low limits; preferably not exceeding .18 to .25 per cent.

27. The greater the amount of metallic alloying elements the more the necessity for lower carbon content. It has been the contention of numerous foundrymen that carbon contents of .15 to .20 per cent do not pour satisfactorily for complex designs. It is the opinion of the Naval Gun Factory, that even though the low carbon content may be conducive to some defects, it is better to have castings that can all be readily repaired by welding; than to have castings with fewer defects but which cannot be satisfactorily repaired by welding.

28. The amount of manganese, nickel, or chromium employed as alloying elements is usually determined by the physical requirements to be met. Molybdenum and vanadium, in quantities commonly used, can fortunately be made to improve physical properties and at the same time produce a material that is weldable.

Low Alloy Castings Susceptible to Air Hardening

29. When it is necessary to weld low alloy castings which are susceptible to air hardening, several procedures may be followed. The castings may be preheated in order to retard the quenching effect of the casting mass surrounding the heated area adjacent to the weld deposit, thus preventing undue hardness.

30. Preheating is usually accomplished by means of oil or gas burners placed at numerous locations about the casting to be welded. Where facilities are available, furnace heating of the casting is preferable as more uniform temperatures are possible. The casting can be removed from the furnace for welding and replaced in the furnace at intervals in order to maintain the temperature within satisfactory limits.

31. For larger castings where furnace facilities are not available, charcoal fires may prove satisfactory. Preheats of 200 to 400 degrees Fahr. are usually sufficient for low alloy content castings. Materials readily air hardenable may require much higher temperatures, however.

32. Repairs are often necessary in difficult places, such as in internal parts of castings where it is imposible for operators to work on preheated material, so resort must be made to other methods. The use of higher currents, in applying the weld, although adverse to conventional practice, is effective. This practice makes a larger heat affected zone but a more gradual hardness gradient from the inner hard area to the outer less hardened or unaffected area. The quenching effect will not be so rapid and stress concentrations will not be as severe.

Multiple Layer Effect

33. By spreading out the heat affected zone resulting from the first layer of weld metal applied, subsequent layers of weld metal can be added over the first while the welded area is still warm. The heat of the second or subsequent layers will penetrate through the first layer and into the heat affected zone sufficiently to draw the major portion of the hardness. By properly timing

this multiple layer sequence, it is possible to produce a weld without detrimental effect in a casting that is normally air hardening. Where large areas are to be welded the cast steel surface can be covered by such a multiple layer method. After having once covered the area in this manner, it is possible to continue welding with no further precautions than are necessary on a similar mild steel material. The additional deposits will, of course, be placed entirely on the weld metal which does not have air hardening properties.

Materials Subject to Air Hardening

34. The sections shown in Fig. 9 demonstrate the possibilities of removing hardness by proper bead sequence. A single layer weld on a steel very susceptible to air hardening (carbon 0.39 per cent, manganese 0.63 per cent, silicon 0.22 per cent, nickel 2.99 per cent, sulphur 0.038 per cent and phosphorus 0.043 per cent) will give Vickers[1] hardness readings up to 579. A second bead reduced the hardened zone resulting from the first bead to 318, but created a second heat affected zone with a hardness up to 469. A third overlapping bead drew the maximum temper of the first two beads to 287 but produced a maximum hardness of 384 in its own small heat affected area. A fourth overlapping layer was sufficient to remove the major portion of the remaining hardness, reducing it to 270-280 as compared with 230-260 of the original material.

PREPARING CASTINGS FOR WELDING

35. In preparing castings for welding, all scale, silicates or other foreign material must be thoroughly removed from the weld area as these substances will contaminate the weld deposit and cause unsatisfactory physical properties. Where the defects are large they may be removed with gas cutting-torches, lances, or air chisels. An experienced chipper can usually follow such defects as small cracks or hot tears by watching the manner in which the chisel chip splits.

36. When no further defect can be detected, the cavity may be ground and polished for etching. In this manner any small associated defects remaining on the cavity surface are readily

[1] Vickers hardness readings are used because of the small area required for test. The Vickers numbers listed are Vickers, Pyramidal Diamond, 30 Kg. load, Objective 2/3 in. They correspond closely to Brinell Hardness numbers up to 300 but are increasingly higher than corresponding Brinell readings from there up.

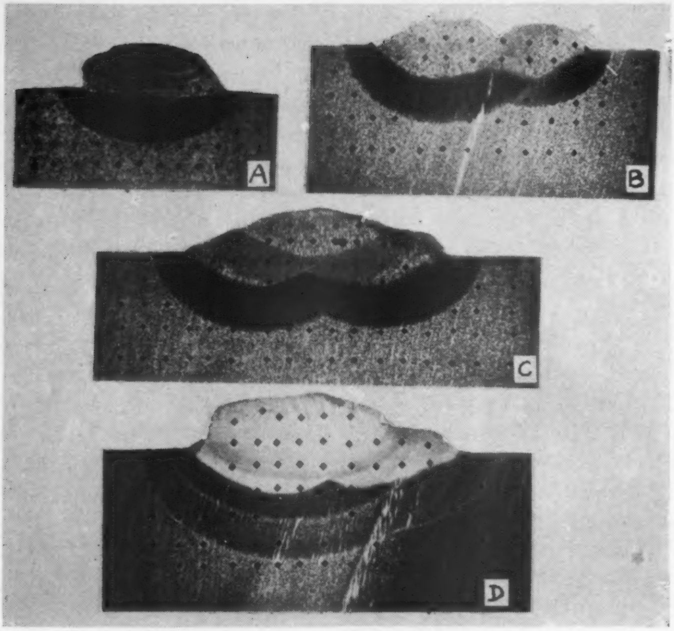

FIG. 9—(A) SINGLE BEAD WELD ON AN AIR HARDENING STEEL. AN EXCEEDINGLY HARD ZONE HAS BEEN PRODUCED IN THE BASE METAL ADJACENT TO THE WELD AS EVIDENCED BY THE VICKERS' HARDNESS TABULATIONS.
(B) A SECOND WELD BEAD HAS BEEN LAYED BESIDE THE WELD SHOWN IN *A*. PART OF THE HARDNESS OF THE FIRST PASS HAS BEEN REDUCED BUT A NEW HARDENED ZONE HAS BEEN CREATED.
(C) A THIRD WELD BEAD HAS BEEN LAYED OVER THE TWO WELD BEADS SHOWN IN *B*. THE HARDENING EFFECT OF THE FIRST TWO BEADS HAS BEEN SUFFICIENTLY REDUCED BUT A SMALL HARDENED AREA BENEATH THE THIRD BEAD HAS BEEN CREATED.
(D) A FOURTH BEAD HAS BEEN APPLIED OVER THE THIRD BEAD OF *C*. BY THE APPLICATION OF A MULTIPLE LAYER SEQUENCE OF WELDING, HARDENED AREAS IN THE PARENT METAL HAVE BEEN REMOVED.

VICKERS HARDNESS VALUES OF WELD SECTIONS

		A—			306	318	306	337	284	275						
					281	269	289	269	303	279	277					
		236	248	517	543	511	401	376	517	550	579	240	238			
		226	238	242	454	499	499	511	481	406	248	238	236			
		230	232	240	252	248	258	242	244	244	244	236	236			
		228	230	238	238	240	242	238	230	238	238	226	234			
		B—				217	207	214	189	199	224	244				
		236	331	459	228	242	234	221	202	200	248	327	281	260		
		236	254	429	469	318	312	429	429	275	318	337	254	258		
		238	228	256	362	419	429	396	279	267	265	250	256	256		
		240	238	236	236	258	258	244	244	242	250	258	254	260		
		234	238	236	234	234	234	265	244	250	254	246	256	263		
C—						192	204	202	194	194	168					
					198	193	200	198	198	196	198	200	215			
236	232	324	254	221	208	204	202	191	199	200	200	217	337	354	254	269
242	240	258	331	315	240	199	228	376	275	210	217	324	348	318	263	272
234	242	234	267	301	303	284	269	246	240	292	318	309	281	250	260	265
240	238	234	238	236	244	240	242	234	238	234	246	246	252	260	258	265
234	230	232	242	242	238	234	244	242	242	242	246	252	254	250	263	267
	D—				167	179	178	178	177	179						
					166	165	166	174	173	166	185	200	185			
	232	242	256	256	174	182	172	172	177	187	193	196	189	240	242	254
	236	236	244	254	254	215	177	179	298	221	232	267	240	269	240	267
	242	236	240	250	250	252	256	275	252	246	265	242	238	234	267	267
	234	236	234	240	246	248	254	248	246	236	269	260	269	269	272	272
	238	236	242	242	236	230	246	228	240	256	260	267	269	275	275	279

detectable. At the same time the groove can be satisfactorily shaped for welding; that is, the walls must not be too vertical, the bottom of the cavity should be properly rounded and surfaces to be welded made reasonably smooth.

37. It is preferable to weld castings in the downhand or flat position. Electrode sizes of 3/16 in. and 1/4 in. are normally used with fairly high currents. This practice does not lend itself to vertical or overhead welding. Where necessary, vertical and overhead welding may be accomplished with smaller rods and lower currents.

APPLICATION IN THIN LAYERS

38. Weld metal should be applied in thin layers rather than in cylindrical beads wherever practicable. By using the layer method, each deposit may recrystalize the metal previously applied, producing a fine grain structure of superior physical properties.

STRESSES PRODUCED BY HEATING AND CONTRACTION

39. Stresses produced by weld heating and contraction are the most important factors to bear in mind. Original cracks, hot tears and shrinkage are often due to the designed shape of the casting, or the pouring practice. Frequently these defects occur in or near the junction of light sections to heavy surrounding stiffeners or in lighter sections due to failure of the mold to collapse. The conditions that caused the original defect may also tend to cause the repair weld to crack.

40. The heavy sections rigidly support the defective areas so little contraction can occur while the weld cools. Stresses produced by welding, therefore, must be largely absorbed in the weld metal itself. These stresses increase accumulatively as the welding progresses. Until the time that the weld is completed its cross sectional area is smaller in comparison with the cross sectional area of the adjacent casting. The incompleted weld deposit therefore cannot stand as large a stress as the casting, although the physical properties of the weld deposit itself may be superior.

41. Unless precautions are taken internal cracks may originate in the weld. These cracks sometimes spread as the welding progresses, two or three layers beneath the deposited surface. The cracks may extend 40 to 90 per cent through the weld and still be detectable only by X-ray or similar examination.

DUCTILE MATERIAL MAY CRACK

42. The improved elastic properties of covered electrode deposits are frequently demonstrated. Yet when the same deposit is made in casting repair, cracks may result with little or no evidence of distortion. This paradox is caused by the complicated stresses that may be set up in welding rigidly supported areas. For example, consider a volume of material acted upon in all directions by forces that are equal and opposite. Although the magnitude of the opposing forces may be varied through wide ranges no distortion will occur as long as the forces remain equal and opposite. No evidence of strain will appear until the cohesive strength of the material has been exceeded. Rupture will then result. Also, with casting repair, contraction may induce heavy stresses that are nearly equal and opposite. The result, may be cracks occurring in a ductile deposit with little forewarning evidence of stress. Such cracks are frequently internal.

REDUCING WELD STRESS CONTENTRATION

43. There are several ways of reducing weld stress concentrations. Preheating causes the weld to cool more slowly so that less stress is set up by the welding operation. Maintenance of the casting, at moderately elevated and relatively constant temperatures, is very advantageous. Expansion and contraction are then held within a small range so that the full effect of shrinkage is not exerted. It is necessary in such cases to work continuously on a job once started until it is completed.

44. On complicated jobs it is preferable to place the finished casting immediately in a furnace for stress annealing without permitting the casting to cool. The additional stresses set up while cooling from the preheat to room temperature are thus avoided.

45. Peening is the most potent means of controlling stresses, preventing cracks and avoiding distortion. This operation must be very carefully done if it is to be effective, however, for misuse may be equally harmful. When peening is to be employed, layers of weld metal should be deposited so that their surfaces are as smooth as possible.

46. Irregularities that occur should be removed by chipping or grinding so equal work will result throughout the deposit from application of the peening tool. All slag or foreign material

must, of course, be carefully removed. Peening should follow the smoothing and cleaning operation as quickly as practical.

47. The peening operation is preferably accomplished by means of a rounded or blunt nosed tool in an air hammer. Rapid, light blows should be used so that the metal will flow smoothly, as in the heading of a hot rivet, rather than by heavy blows which may tend to tear or rupture the metal. By peening immediately after welding, while the deposit is still hot, less work is required to accomplish a given result and the metal is more ductile so that detrimental effects are less likely to occur. Peening at this time also prevents contractive stresses which would possibly cause cracking or distortion.

Peening Precaution

48. If the material being welded is subject to air hardening, care must be taken not to peen the first two or three layers as blows from the peening hammer will be inducive to cracking in the hardened zone beneath the weld deposit. Where the cavity to be repaired extends all the way through the casting the first few layers of weld metal closing the void should not be peened. Sections of this nature may be too thin to withstand the mechanical working and subsequent cracks may posibly develop.

49. Care must be taken that no undue irregularities in the weld surface are peened down as this will cause folds in the underlying metal which will be covered over and remain as a void in the deposit. Excessive peening must be avoided as compressive forces can be introduced which are detrimental and in extreme cases may cause warping in the reverse direction to that anticipated. Personnel can be trained so that they can perform peening operations effectively. Little supervision is required once a suitable routine has been established. If peening is properly done it is very helpful in preventing distortion and in the production of satisfactory weld repairing.

Hardened Areas Adjacent to Weld

50. Castings which have been welded so that hardened areas exist adjacent to the weld should be heat treated in order to relieve this condition. The usual practice of heating slightly above the critical temperature and furnace cooling is a satisfactory method. In some cases it may be practical to weld castings before any heat treatment. Deleterious areas resulting from welding will

then be removed during the normal heat treatment cycle subsequently performed on the castings. Such practice must be used with caution, however, as green castings may contain heavy initial stresses, and in their coarse-grained, brittle condition are vulnerable to cracking.

Stress Relieving

51. Stresses induced by welding may be satisfactorily relieved in most cases at temperatures of 1100 to 1200 degrees Fahr. There is no change in microstructure at these temperatures but the tensile strength of most low alloy steels is reduced to 6000 or 8000 lbs. per sq. in. so that residual stresses in excess of this amount will adjust themselves. Temperatures of this magnitude are usually not sufficient to cause warping of the casting due to its own weight and should not cause heavy scaling.

52. The usual procedure is to heat the casting slowly with the furnace, hold for one hour per inch of thickness of the heaviest section and cool in the furnace. Lower temperatures may be equally effective if employed for sufficiently long periods of time. The required holding periods increase rapidly with lower temperatures so this procedure is usually inadvisable.

AN EXAMPLE OF WELD REPAIR

53. Naval Gun Factory castings are necessarily of high quality in order to be satisfactory for the exacting requirements of ordnance use. Due to the complicated nature of some parts, however, casting difficulties are sometimes encountered. As a demonstration of the practicability of the foregoing principles an example of weld repair is cited.

54. A number of carriages for a 5″/38 caliber gun (main supporting member for the gun and associated mechanism) Fig. 10A had been cast, heat treated and finished machined ready for assembly before the X-ray equipment was installed. After X-ray inspection was established it was found that a great many of these carriages had extensive defects in a highly stressed area near the base. Examination of pilot castings and extensive machine work in the defective area failed to disclose the internal hot tears, although a number of them extended 80 to 90 per cent through the finished cross sectional area.

55. These finished carriages weigh approximately 3000 lbs. In order to reclaim these parts, repair had to be effected without

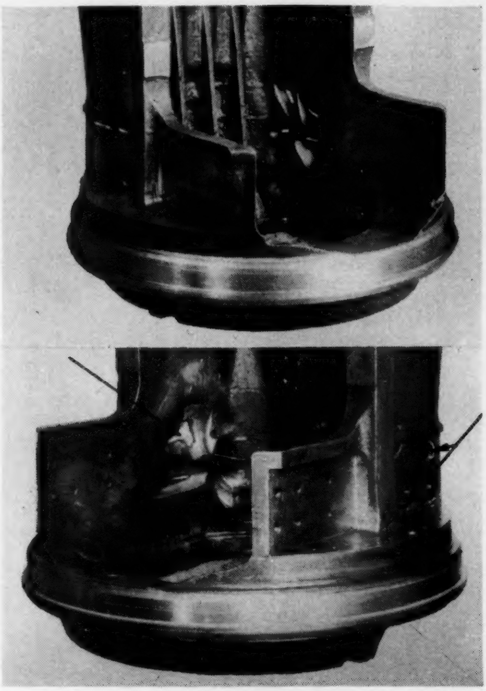

FIG. 10—(A) CARRIAGE CASTING FOR 5-INCH 38 CALIBER GUN. DEFECTIVE AREAS HAVE BEEN REMOVED.
(B) FIVE-INCH CARRIAGE CASTING WITH LARGE DEFECTIVE AREAS NEAR BASE.

appreciable distortion. After considerable experimenting on sample pieces and pilot models, the repair procedure described below was established.

Removing Defective Areas

56. Castings were X-rayed in all defective areas and the defects traced on the outside of the casting. Chippers using heavy air operated chisels removed these defective areas. This operation was followed by grinding, buffing and etching in order to further determine that all visible cracks, tears or voids were completely removed, see Figs. 10B, 11 and 12. If the defective area did not extend entirely through the casting the remaining cross sectional area was X-rayed in order to detect further tears that might exist beneath the etched surface. This procedure was

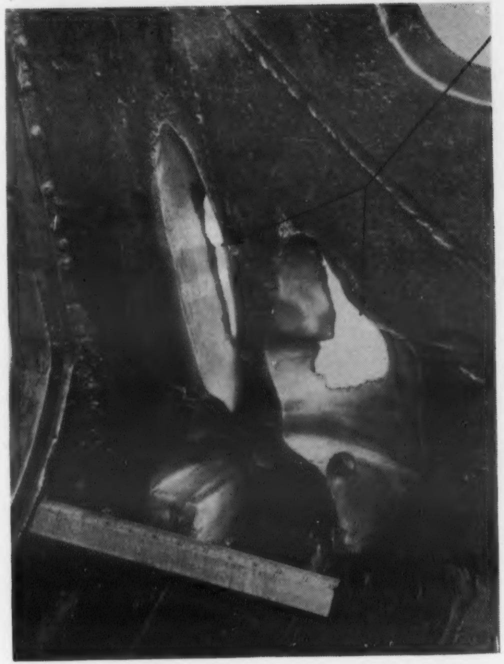

FIG. 11—LEFT—SECTION OF CASTING SHOWING AREAS FROM WHICH DEFECTS HAVE BEEN REMOVED. FIG. 12—RIGHT—CASTING WITH DEFECTIVE AREA REMOVED. SURFACES HAVE BEEN POLISHED AND ETCHED DURING COURSE OF INSPECTION.

repeated until all defects were removed. The casting was then ready for welding.

Welding Operation

57. The carriages were placed in a convenient position for welding and preheated to between 200 and 300 degrees Fahr. A definitely timed welding cycle was started and continued at a rate that would maintain the casting at this temperature until the weld was completed. The welding cycle consisted of applying a layer of weld metal in the defective area, removing the slag

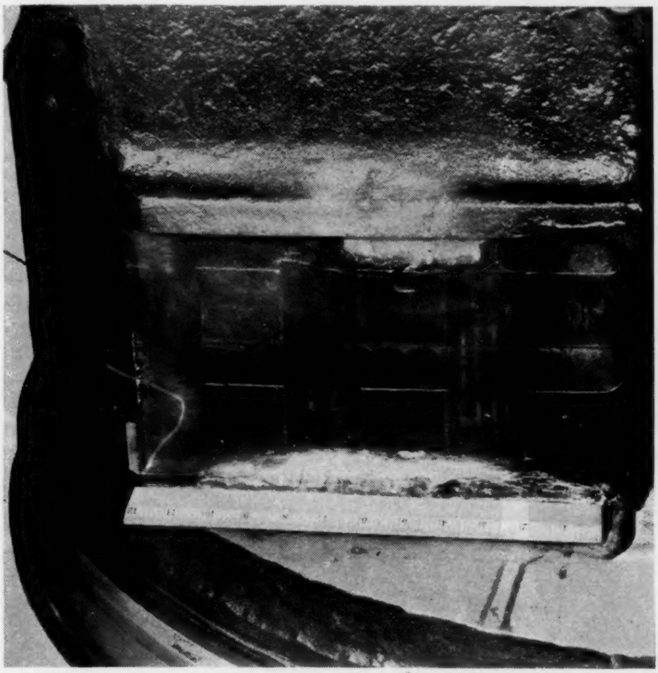

FIG. 13—WELDED AREA PARTIALLY COMPLETED. SLAG AND IRREGULARITIES HAVE BEEN REMOVED FROM WELD SURFACE IN PREPARATION FOR PEENING.

from the weld, grinding, or chipping irregularities from the weld surface when necessary and chipping out any defects from the weld deposit, such as gas holes, slag inclusions, etc., Fig. 13.

58. Following this preparation, the weld was peened by an especially trained operator who had been taught the correct amount of peening from practicing on pilot samples. A crew of men

FIG. 14—LEFT—COMPLETED WELD REPAIR. REINFORCEMENT HAS BEEN REMOVED, SURFACES POLISHED AND PARTLY ETCHED. FIG. 15—RIGHT—COMPLETED WELD REPAIR. SURFACE EXAMINATION AND X-RAY DISCLOSE NO FURTHER DEFECTS.

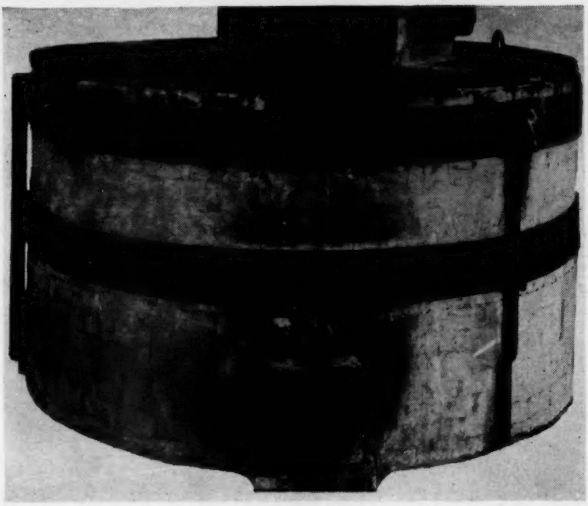

FIG. 16—STRESS RELIEVING FURNACE DESIGNED FOR TREATING REPAIRED PORTION OF CARRIAGES.

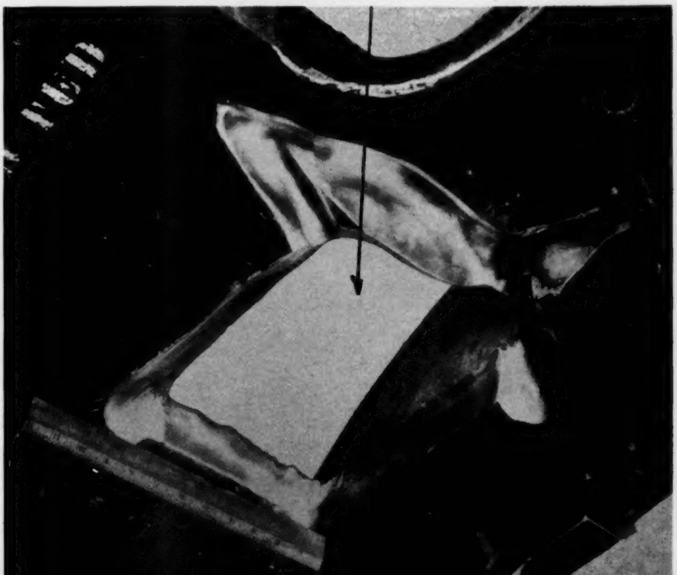

FIG. 17—WHERE AN AREA CONTAINS NUMEROUS SMALL TEARS IT IS ADVISABLE TO REMOVE THE ENTIRE SECTION AND REPLACE WITH A PLATE OF SIMILAR SECTION AND PROPERTIES.

trained for the welding, chipping and grinding operations performed their successive duties in the required order on several castings. The number of castings worked upon at a time depended upon the size of welds but care was taken so the time interval automatically maintained the desired temperature in each casting. All welds were reinforced or built up approximately 1/4 in. thicker than the casting before being permitted to cool.

59. After the welding was completed and the casting had cooled sufficiently, the excessive weld metal was removed, the area polished, ground, etched and examined for surface defects, (Figs. 14 and 15). All welded areas were then X-rayed. If any further defects in the casting or cracks and tears in the deposited weld metal had developed during the welding operation, the defects were removed and the repair process repeated. In this manner all questionable areas were eliminated.

Stress Releaving Treatment

60. After completion, the carriages were placed in an especially constructed stress-relieving furnace. This furnace, Fig. 16, was designed so that heat would be applied only to the repaired area and no oxidation resulted on the trunnion bearing supports. The heat gradient was gradual between the heated portion and the external sections so no serious stresses were introduced. The welded area was gradually heated to a temperature of approximately 1100 degrees Fahr. during a period of 8 hours, held at this temperature for 3 hours and permitted to cool in the furnace for a period of 12 hours. The carriage was then removed and the light oxide buffed from the finished machined surfaces.

61. In cases where warpage beyond the permissible tolerances resulted the parts were ground undersize until the low spots were removed. The undersize pad or bearing races was then electroplated to the required dimensions. This procedure was found necessary only in cases where 20 to 30 lbs. of weld metal had been added or where residual stresses were already in the casting.

Defective Areas Replaced

62. On some carriages where the defective area consisted of numerous small tears, the entire questionable section was removed (as shown in Fig. 17) and replaced by welding in a plate having similar physical properties and cross sectional area. After com-

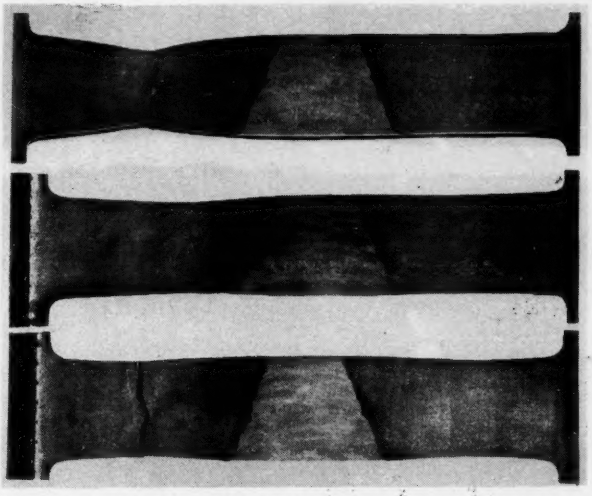

FIG. 18—FULL SECTION TENSILE TEST DEMONSTRATING SUPERIOR TENSILE STRENGTH OF WELD METAL. RUPTURE OCCURRED AT 62,000 TO 67,000 LBS. PER SQ. IN. DEPENDING UPON THE CASTING STRENGTH.

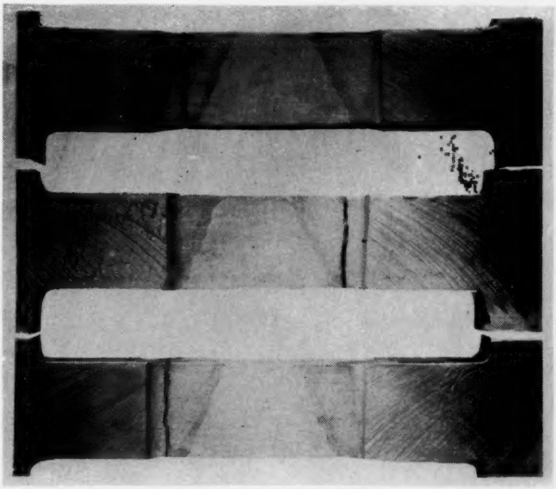

FIG. 19—TENSILE SPECIMEN REDUCED IN AREA OF WELD TO CONCENTRATE APPLIED STRESS IN THE DEPOSIT. WELD IS STRONGER THAN CAST SECTION. RUPTURE OCCURRED AT 62,000 TO 70,000 LBS. PER SQ. IN. AS DETERMINED BY THE CASTING STRENGTH.

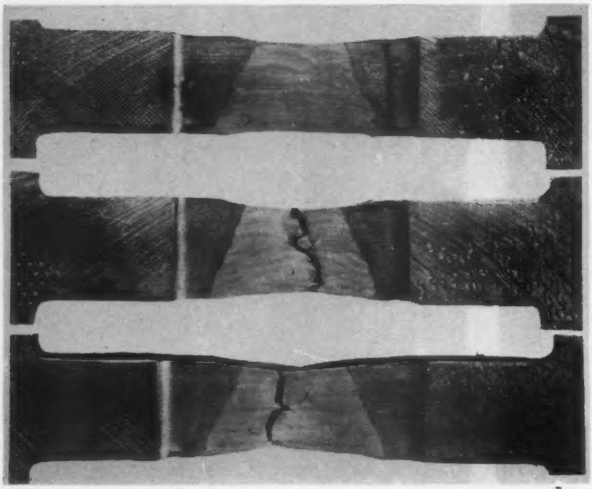

FIG. 20—TENSILE SPECIMEN MACHINED SO MINIMUM SECTION IS AT CENTER OF WELD. RUPTURING STRESS OF WELD METAL 70,000 TO 75,000 LBS. PER SQ. IN.

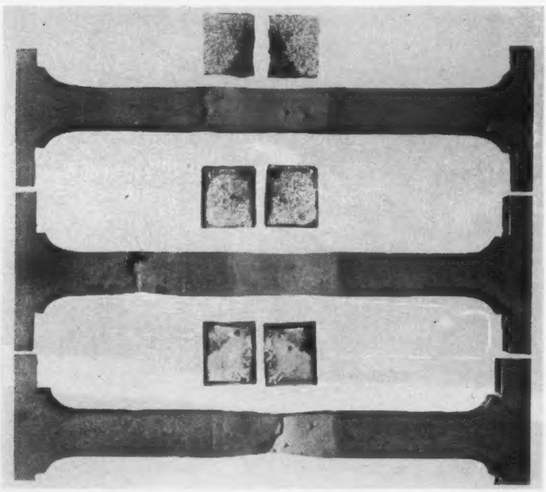

FIG. 21—TENSILE IMPACT TESTS SIMULATE FIRING LOADS. THE STRIKING VELOCITY OF LOAD WAS 21.35 FEET PER SECOND. ENERGY OF RUPTURE 1668, 1718 AND 2141 FOOT POUNDS FROM TOP TO BOTTOM, RESPECTIVELY. FRACTURES OCCURRED AT IMPERFECTIONS IN WELD OR CASTING AS SHOWN BY THE RUPTURED SECTION.

pletion, the carriages went into the regular assemblies. The assembled guns were given their proof firing test and all repaired areas again X-rayed. The additional examination was to determine whether any appreciable cracks had occurred between the time welding was finished and stress relieving was completed or during proof firing.

Final X-ray Check

63. Final X-ray checks of the castings so repaired have dis-

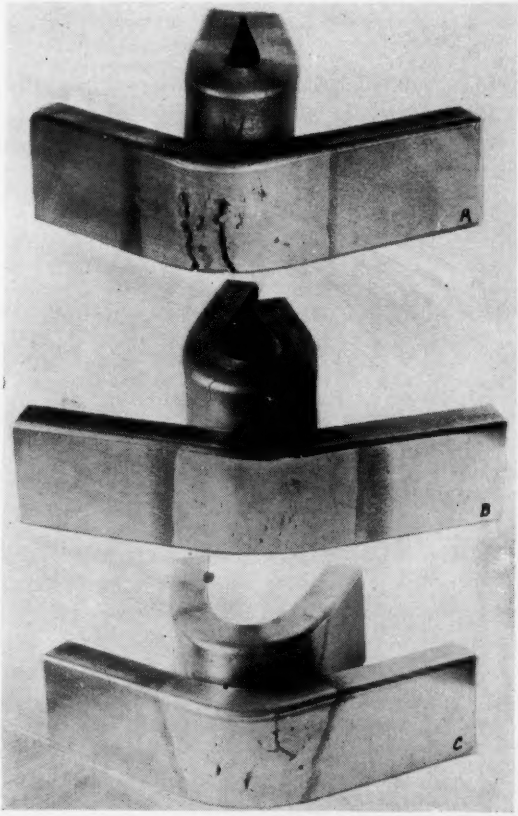

FIG. 22—(A) FREE BEND SPECIMEN OF WELDED STEEL CASTING. ELONGATION BEFORE STRESS RELIEVING, 24 PER CENT. THE SAME SECTION STRESS RELIEVED 41 PER CENT ELONGATION. (B) ELONGATION BEFORE STRESS RELIEVING, 9 PER CENT. THE SAME SECTION STRESS RELIEVED 44 PER CENT ELONGATION. (C) ELONGATION BEFORE STRESS RELIEVING, 21 PER CENT. THE SAME SECTION STRESS RELIEVED 40 PER CENT ELONGATION.

closed no further defects after being subjected to proof firing tests, in which larger powder charges were used than are employed in regular service firing. Tests demonstrating the desirable physical properties obtained in this repair job are shown by Figs. 18, 19, 20, 21 and 22. Weld metal performance in physical tests are usually demonstrated by perfect deposits made under laboratory conditions. The above illustrated tests were taken from shop production rather than selected specimens and demonstrate the relative merits of weld metal and cast metal obtained under average production condition.

FOUNDRY APPLICATIONS OF X-RAY AND WELDING

64. It is believed that the X-ray can be of material aid in helping the foundryman to control his foundry practice so that sounder castings will be consistently produced. Welding if properly applied can be used effectively to repair extensive defects which may occur in castings from time to time. The soundness of weld repair can be further assured by X-ray examination. Not only can welding be used for repair of defects but complicated castings may be molded in several simplified sections and subsequently assembled by welding them together to form a less expensive and more dependable final product.

COOPERATION OF FOUNDRYMAN AND WELD DESIGNER

65. The foundryman and the weld designer have in too many cases been rivals since the extensive introduction of weld fabricated rolled steel to replace castings. It appears, however, that cooperation between these two processes will offer advancement in steel construction. Heavy complicated sections of sufficiently uniform thickness may be readily cast. Large light weight sections are rolled, drawn and weld fabricated advantageously. In numerous cases, an assembly, partly of rolled stock and partly of steel castings will be the optimum in the effective use of metal and in fabricating costs.

66. The X-ray and welding are two of the newer tools of the foundryman. Thus far we have had some very successful applications but the field is still naissant. With proper design and carefully controlled procedure, stronger, lighter and more uniformly high quality steel products may be expected.

DISCUSSION

C. W. BRIGGS[1]: There are a few suggestions I should like to make. Figs. 5, 6 and 7 show reproductions of x-ray radiographs. I believe it is a mistake to make positive copies of radiographs for publication. Foundrymen, when using x-ray or the gamma ray radiography to detect defects, always examine the films, and have become accustomed to seeing defects appear as dark lines and dark objects. I feel that we ought to maintain a standard procedure thereby eliminating confusion and always make a negative print for publication, so that conditions will be similar to the actual films that we see on the foundry floor.

In connection with the statement in paragraph 27 where it says, "It is the opinion of the Naval Gun Factory, that even though the low carbon content may be conducive to some defects, it is better to have castings that can all be readily repaired by welding than to have castings with fewer defects but which cannot be satisfactorily repaired by welding." It seems that, after all, foundrymen are primarily interested in producing castings that are free from defects. If a casting is free from defects, there will be no necessity for welding. I would imagine that the first thing to do would be to aim toward that end instead of trying to produce a casting that can be welded regardless of casting defects.

In paragraph 28, it is stated that, "Molybdenum and vanadium in quantities commonly used, can fortunately be made to improve physical properties and at the same time produce a material that is weldable." I have heard many opinions and have seen a considerable number of written statements, such as the above, in which a considerable point is made that carbon steel castings are not weldable. However, I have never seen actual confirming data published. I would like to have someone publish data on whether or not carbon steel castings are weldable. Probably the authors mean that such castings do not weld with as much ease as other castings.

In paragraph 39, it is stated, "The conditions that caused the original defect may also tend to cause the repair weld to crack." I would like the authors to present a little more information on this point.

MR. ASH: In reply to Mr. Briggs, it does seem more logical to represent radiographs in the condition in which the routine interpretations are made, namely, the negative condition. However, to make a negative print, it is necessary to reproduce the original negative twice, and it has always been my experience that much detail and definition is lost during these operations. Many of the small markings are lost completely in these transfers. Furthermore, very little effort is required to make interpretations from a positive print. The positive prints represented in this paper were made principally to show defects as clearly as possible.

I will attempt to further clarify what is meant by the statement in the latter part of paragraph 39. Many of the defects encountered were shrinkage tears. These tears, varying from one to 10 in. in length, were formed in an area where a relatively thin plate jointed a heavier section.

[1] Division of Physical Metallurgy, U. S. Naval Research Laboratory, Washington, D. C.

During the original solidification of the casting, the plate solidified first and as solid contraction proceeded, produced a shrinkage tear in the filleted area where the metal was not yet sufficiently strong to resist the stresses created.

During the welding of a cavity, the molten weld metal is surrounded by solid metal of the casting. In cooling down, the latter imposes severe stresses upon the weld and these stresses often exceed the high temperature (very near the solidification range) strength of the weld metal which results in tears in the weld.

The general principle involved is practically the same in both cases, namely, tears occur in the area to solidify last.

J. M. SAMPSON[3]: We have an outfit at Schenectady that we use particularly on our turbine work. The paper I am to present may answer some of Mr. Briggs' questions. We of the staff of the General Electric Company have had many arguments among ourselves as to the weldability of steel castings. The work which is presented in my paper, was done two or three years ago to clear up several points. One of them, in which I was particularly interested, was the weldability of steels with carbon contents higher than 0.30 per cent. All the tests that we made were on carbon steels running from 0.31 to 0.39 per cent carbon. I believe the tests proved quite conclusively that the idea that a carbon steel casting has to have a low carbon to make it perfectly weldable, is wrong, although some of us in the foundry, unfortunately, have not been able to convince our own welding engineers of that fact.

While I do appreciate Mr. Briggs' contention that the foundryman should do everything possible, to the extent of his ability, to produce a casting that does not have to be welded, I have yet to see one major casting, that has not required some welding work.

My own opinion, which is supported by many others, is that we can produce castings with the higher carbon contents running, say, from 0.30 to 0.35 per cent carbon, with greater ease, with less inherent difficulties from the foundryman's standpoint and with a much better appearance than we can castings with the carbon contents, say, below 0.25 per cent.

We have found the x-ray of almost invaluable service to us. There is no question but that its use has made us tighten up in our practices. We have found that we had to change our methods of gating and we have had to be a lot more ingenious in the use of chills. I am not saying whether these chills are internal or external. We have learned, however, supporting Chairman Hall's contentions, as advanced for the past number of years, that the use of internal chills is no doubt quite hazardous, and we have resorted to risering the bottom sections. This has often meant a fight with the designing engineers to get them to modify the design somewhat so we could get risers down at the bottom of heavy sections which we formerly used to chill.

The x-ray has been especially valuable, particularly when we use a stereoscopic view. Our staff has worked out a rather ingenious method by which they can see quite definitely how deep the defect is. Then they

[3] General Electric Co., Schenectady, N. Y.

can explore the defect with a drill and come to a definite conclusion as to whether it should be welded.

P. E. McKINNEY[3]: I am very much impressed with the increased justification for welding, as disclosed by radiographic examination. As the authors have stated, welding has been limited practically to the repair of minor surface imperfections on quality castings in times past. With a better knowledge of what the major defect is, the engineer, who is responsible for the use of the casting, is justified in going to a much greater extent, with entire safety, in sanctioning welding.

The question of welding has been a very peculiar one as between repairs of so-called defective castings and the making of production welds. In times past, we have found engineers and users of castings very much exercised over contemplated welding in a place on a casting, which is cast in one piece, while they would without any conscientious scruples permit in a weldment joining two pieces. Intelligently applying modern welding technique to the rectification of imperfect castings is certainly a step in the right direction and should bring castings into greater popularity and use for engineering applications.

CHAIRMAN J. H. HALL[4]: I notice that in paragraph 15 the authors say "Some of the defects observed were of a nature subject to propagation. * * *" Are we to understand by this, that they were likely to grow in service?

MR. ASH: Yes, that is right.

CHAIRMAN HALL: I was very much impressed, in connection with Fig. 17, at the willingness of the engineers who were concerned with these castings to allow a good sized piece to be cut completely out and a piece of plate of similar composition and nature to be welded in. We are certainly gaining a lot, as Mr. McKinney says, in the willingness of engineers to accept welds in castings. I suppose also, as Mr. McKinney pointed out, the use of structures where two castings are welded together has gradually awakened the engineer to the fact that if you can weld two castings together, you can certainly weld up a hole in a casting.

The statement of paragraph 49, "Personnel can be trained so that they can perform peening operations effectively," is certainly true, but the statement, "Little supervision is required once a suitable routine has been established," I believe, is one that needs a little qualification. I have not seen a welder or a man doing peening that does not require more than a little supervision at well chosen intervals.

MR. McKINNEY: Referring further to page 9, particularly paragraphs 26 and 27, the statement is made that "Carbon being the most potent alloying element, should be kept within satisfactorily low limits, preferably not exceeding 0.18 to 0.25 per cent."

I fully agree in principle that when the welder is only thinking of a weld, that this is a very good rule to follow. Mr. Sampson has pointed out the advantages, from the foundryman's standpoint, of the higher brackets of carbon. Another thing, that must be taken into considera-

[3] Bethlehem Steel Co., Bethlehem, Pa.
[4] Taylor-Wharton Iron & Steel Co., High Bridge, N. J.

tion from time to time, is that the designer requires certain definite strengths in many castings.

The A. S. M. E. Boiler Code, under proper restrictions, places an upper limit for carbon of 0.30 per cent and in some cases specifications permit 0.35 per cent as the limit for weldability without special sanction.

There is a great deal to be done in the development of welding technique and temperature control of the piece being welded, that is, preheating, or at least a control of the temperature proper during the welding operation, the type of wire and the type of technique.

It would be unfortunate if we accept as an axiom that carbon must be within the range of 0.18 to 0.25 per cent. We know that in actual welding operations with good welding technique, we many times very successfully weld very much higher carbon and even alloy steels.

The Boiler Code and other authorities have set up quite elaborate tests that are being carried on more and more in foundries that are interested in doing a good welding job and improving the quality of the welds being produced. They have set up quite elaborate welders' qualification tests on carbon steels and, in some cases, on alloy steels. While they probably go a little further than necessary, the principle of such methods of proving the welding technique is sound and will many times permit us to weld a combination of alloy contents with perfectly satisfactory results and without limiting ourselves to the restrictions that are given in this paper.

CHAIRMAN HALL: Further in connection with the statement in paragraph 20, "During the past several years, however, a very satisfactory type of mild steel, covered welding electrode has been developed." A lot of manufacturers sell coated welding rods for welding carbon steel, and there are quite a number that have good rod.

MR. ASH: In that paragraph to which Mr. Hall just referred, we are not referring to any particular rod, but mean a class rather than make of electrode. There are several makes that meet Navy requirements.

The Wear Resistance of White Cast Iron

By O. W. Ellis,* J. R. Gordon,** and G. S. Farnham,**

Toronto, Can.

1. During the past five years, so many inquiries were made of the senior author regarding the resistance to wear of white or chilled cast iron, and so little information appeared to have been published on this subject, that it was deemed desirable to conduct an investigation along these lines.

2. After considerable discussion it was decided to adopt a ball-mill test for measuring the wear of the materials it was designed to investigate. Of course, it was fully recognized that the results of such tests would be unlikely to afford a clue to the wear resistance of the materials forming the balls in situations other than ball mills.

Method of Testing

3. The tests were conducted in a Greey, motor-driven, six-jar mill, designed to take end-discharge porcelain jars of standard dimensions with a capacity of one U. S. gallon. The outside dimensions of the jars were 8.75 inches diameter and 9.60 inches height. The jars were rotated at 60 r.p.m.

4. Several grinding media were tried before the authors decided upon 1/4 inch silicon carbide grain (supplied by Canadian Carborundum Company, Ltd.) because of its high rate of abrasion. Most of the other materials tried gave a rate of wear so slow that appreciable losses were not obtained in reasonable times.

5. The method of test adopted required a charge in each jar of 9 balls of 1 inch diameter (weighing in all about 1 1/4 lb.), 4 pounds of 1/4 inch silicon carbide grain, and 1 1/4 pounds of water.

* Director of Metallurgical Research, Ontario Research Foundation, Toronto, Can.

** Research Metallurgist, Ontario Research Foundation, Toronto, Can.

Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

The jars were then closed, placed in the mill, rotated 160,000 times (as indicated by a counter), and finally removed from the mill. The charges were then removed from the jars, and the balls dried and weighed, after which they were re-introduced into the jars with fresh silicon carbide and water and subjected to a further abrasion (160,000 revolutions). The tests were continued until the balls had lost about 10 per cent of their original weight.

6. Prior to their introduction into the jars, the average diameters of the balls were determined. By using these values the initial superficial areas of the balls were calculated, the wear of individual balls being expressed finally in loss of weight in milligrams per square centimeter of initial surface.

CRITICISM OF METHOD OF TESTING

7. Rosenberg[1] has described the results of abrasion tests of steels in a ball mill in which standard Ottawa silica sand (20-30 mesh) and Illinois glass sand were used as grinding media. The results obtained were quite erratic—so much so, in fact, that Rosenberg felt that they might be dismissed as of qualitative value only. He concluded that the ball mill held little promise as a laboratory machine for testing the resistance of metals to abrasion because, on the one hand, "it is not sufficiently sensitive to show positive differences in resistance to wear," and, on the other hand, "it is not sufficiently accurate to give check results. In addition to these disadvantages the making of the spherical specimens is a costly and tedious process."

8. In so far as sensitivity is concerned, the authors believe that by the use of a more "positive" medium (for example, silicon carbide) any defect in sensitivity can be largely, if not completely overcome, as the present tests quite clearly demonstrate. One has only to compare, for example, the loss of weight of a 2.5 per cent carbon alloy (namely, 118 milligrams per square centimeter per 1,600,000 revolutions) with that of a 3.5 per cent carbon alloy (namely, 175 milligrams per square centimeter per 1,600,000 revolutions) to appreciate the sensitivity of the ball-mill test when a suitable medium is employed in grinding.

9. It must be admitted that check results are unobtainable in successive tests. For this reason it is essential to employ balls of known composition as standards for comparison from test to test. This practice is justified for two reasons: first, close checks

[1] Transactions A.S.S.T., 1930. vol. 18, pp. 1093-1124.

can be obtained in any given test on balls cast from one melt, and, second, just as close checks can be obtained in any given test on balls of similar analysis but cast from different melts.

10. The machining of spherical test samples is, of course, a costly and tedious process. The casting of balls, however, suffers from no such failing—it is an inexpensive and relatively simple operation.

11. The use of the ball mill seems, therefore, to be vindicated

Table 1

Material	C %	Si %	Mn %	S %	P %
West Coast hematite pig iron	3.66	3.54	0.13	0.008	0.015
Washed metal	3.65	....	....	0.025	0.025

in the particular case now under discussion. Further, it is not impossible that its use could be extended to the testing of other alloys.

12. Since it was desired to vary as widely as possible the composition of the alloys to be tested, the materials for the charges were selected with this in mind. Swedish wrought iron, washed metal, and West Coast hematite pig iron formed the basis for every melt. Analyses typical of the washed metal and the pig iron are shown in Table 1, mainly to indicate the comparative freedom of these materials from sulphur and phosphorus.

13. The use of varying proportions of the above ingredients eliminated the necessity for adding carbon to the melts as coal or charcoal and reduced the ferro-silicon required. The necessary manganese was introduced as ferro-manganese.

14. At first, troubles were caused by blowholes forming in the low-silicon alloys. These, however, were overcome by adding 0.10 per cent aluminum to the melts just before pouring. This practice was followed in all cases so that variations due to the presence or absence of this element might be uniformly avoided.

15. The charges varied from 10 to 12 pounds in weight and were melted in graphite crucibles lined with sillimanite. The life of these sillimanite linings ranged between 6 and 12 melts. Owing to its ready attack by manganese oxide, sillimanite was replaced by magnesia (bonded with magnesium chloride) when high-manganese melts were in course of preparation.

16. A pouring temperature of 2732 degs. Fahr (1500 degs.

Cent.) was used consistently throughout the experiments, this being checked with a Cambridge optical pyrometer.

17. A series of preliminary wear tests was conducted on alloys containing 2 per cent and 3 per cent of carbon and varying proportions of manganese (0.25 to 1.00 per cent) and silicon (0.75 to 1.25 per cent). In these experiments cylinders ¾ inch long.

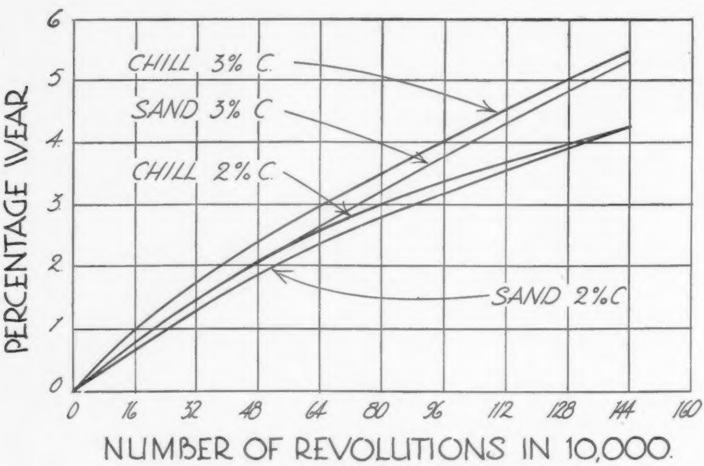

FIG. 1—WEAR TESTS OF CHILL AND SAND CAST IRONS.

which had been cut from sand and chill cast bars ¾ inch in diameter were used. The results are dealt with briefly in paragraphs 18 to 20. In all the other wear tests sand-cast balls, ¾ inch in diameter, were used. Concurrent with the casting of these balls, sand- and chill-cast bars, ¾ inch in diameter, were poured. Samples cut from these bars were the subjects of malleabilizing experiments, the results of which are to be described in a separate paper.

18. A considerable amount of work was carried out before balls were used as test samples in place of cylinders. In all, twelve alloys were subjected to tests, the results of some of these being shown graphically in Figs. 1, 2, and 3.

19. The following conclusions were reached:

(a) That sand-cast cylinders, provided they were white throughout, were more resistant to wear than chill-cast cylinders.

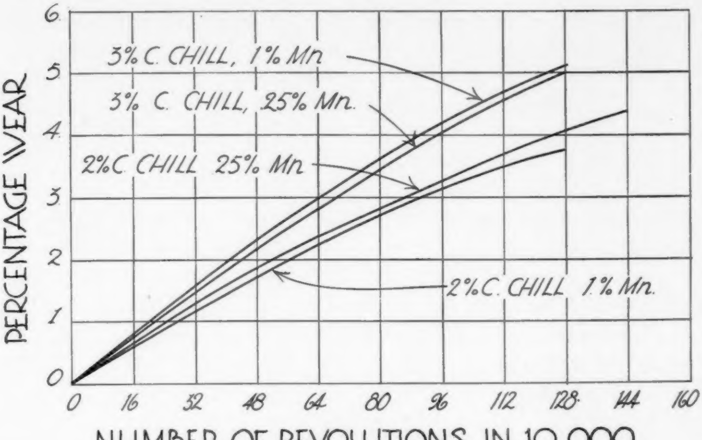

FIG. 2—WEAR TESTS OF CHILL CAST IRONS WITH VARYING CARBON AND MANGANESE PERCENTAGES.

(b) That the irons containing 2 per cent of carbon were more resistant to wear than those containing 3 per cent of carbon.

(c) That increase of manganese from about $\frac{1}{4}$ per cent to

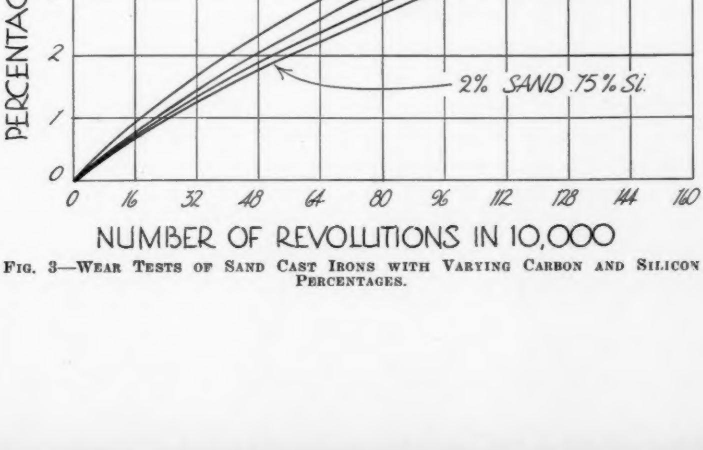

FIG. 3—WEAR TESTS OF SAND CAST IRONS WITH VARYING CARBON AND SILICON PERCENTAGES.

about $1\frac{1}{2}$ per cent had but little effect upon the wear resistance of irons containing 2 or 3 per cent carbon.

(d) That increase of silicon from $\frac{3}{4}$ per cent to $1\frac{1}{4}$ per cent, provided the castings remained white throughout, had but little effect upon the wear resistance of 2 per cent or 3 per cent carbon irons.

20. In the course of these tests a somewhat interesting phenomenon was observed. The samples were marked with an electric pencil. At first, it was expected that these marks would be erased during test. To everyone's surprise, however, the marks not only increased in visibility but stood out in greater and greater relief as the tests proceeded. Microscopic examination of the metal in the vicinity of the marks showed that partial decarburization had occurred and that martensite had formed as a result of marking, so that wear resistance was increased.

TESTS ON BALLS—EFFECTS OF CARBON, SILICON, AND MANGANESE

21. A series of twelve alloys was prepared, six having a carbon content of about $2\frac{1}{2}$ per cent and six a carbon content of about $3\frac{1}{2}$ per cent. In these the proportions of silicon and manganese were varied, the former in two steps ($\frac{3}{4}$ per cent and $1\frac{1}{2}$ per cent), the latter in three steps ($\frac{1}{4}$ per cent, $\frac{1}{2}$ per cent, and 1 per cent). The compositions of the alloys, as determined by chemical analysis, were as follows (Table 2).

22. The wear numbers referred to in Table 2 are the sums of the losses in weight in milligrams per square centimeter of original ball surface, which occurred during 5 and 10 standard runs of 160,000 revolutions, respectively (see para. 5).

23. Chemical analysis and microscopic examination of the $\frac{3}{4}$ inch-diameter, sand-cast bars of the $3\frac{1}{2}$ per cent carbon alloys showed them to contain appreciable proportions of graphite. The fractures of the bars were mottled, as were those of the balls. The graphite in these balls accounted for their relatively high wear numbers and for the somewhat wide variation in the wear resistance of individual balls of similar analysis (cf. remark in para. 9). But graphite was not the only cause of the somewhat wide variation in the wear resistance of individual, high-carbon balls of similar analysis, whether mottled or gray. These tests show that the higher their carbon content, the greater were the variations in the wear resistance of individual balls of otherwise similar analysis. This point was brought out very clearly in tests

on commercial balls (see Table 4). These balls, which were white, containing approximately 3½ per cent of carbon, were found to wear rather more rapidly than balls made at the Foundation, and furthermore were found to vary considerably from ball to ball in their wear resistance.

24. In so far as the 2½ per cent carbon alloys are concerned,

Table 2

ALLOYS USED IN TESTS TO DETERMINE EFFECTS OF C, SI, AND MN ON WEAR OF SAND-CAST BALLS.

Alloy No.	T. C. %	G. C.* %	Si. %	Mn. %	Average Vickers Hardness Number	Wear Numbers	
1	2.58	0.02	1.14	0.23	434	54	118
2	2.51	0.03	1.13	0.47	458	57	120
3	2.64	0.04	1.28	0.93	458	53	122
4	2.50	N.D.**	0.65	0.18	412	58	120
5	2.47	0.01	0.66	0.47	438	56	118
6	2.63	0.01	0.66	1.09	458	54	118
7	3.43	2.70	1.14	0.23	202	64	175
8	3.42	2.76	1.13	0.50	210	66	174
9	3.54	2.71	1.13	1.10	227	68	173
10	3.67	1.42	0.82	0.24	198	86	203
11	3.53	1.70	0.73	0.52	244	91	206
12	3.53	N.D.	0.75	1.02	226	81	191

*¾-inch bars. ** Not determined.

it can be said that variations of manganese and silicon within the limits ¼ to 1 per cent and ¾ to 1¼ per cent, respectively, are practically without effect upon their wear resistance.

25. In the case of the 3½ per cent carbon alloys, however, those of higher silicon content (1¼ per cent) were far more resistant to wear than those of lower silicon content (¾ per cent). This somewhat anomalous behaviour is dealt with in detail later (see para. 38). Speaking generally, the balls with high wear numbers became pitted during test, while those with low wear numbers remained relatively smooth. This was true, not only of the balls of this series, but of all the balls.

26. A series of eleven alloys was prepared, of which seven contained copper. Their compositions, as determined by chemical analysis, were as given in Table 3.

27. The ¾-inch, chill-cast bars of copper-free iron contained no graphite. Those of some of the copper-bearing irons showed

traces of dendritic graphite in the neighborhood of shrinkage cavities present at the axes of the bars.

28. The foregoing tests show that no advantage in wear re-

Table 3

ALLOYS USED IN TESTS TO DETERMINE EFFECTS OF C AND CU ON WEAR OF SAND-CAST BALLS.

Alloy No.	T.C. (%)	G.C.** (%)	Si. (%)	Mn. (%)	Cu. (%)	Average Vickers Hardness Number	Wear Numbers	
13	2.18	N.D.†	0.70	0.53	....	434	68	140
14	2.08	N.D.	1.17	0.48	....	399	65	132
15	3.02	N.D.	0.75	0.55	....	511	71	152
16*	3.00	1.40	1.28	0.51	....	446‡	80	215
17	2.00	0.03	0.75	0.48	1.00	422	67	140
18	2.00	0.03	0.75	0.50	1.92	444	66	140
19	2.03	N.D.	0.75	0.48	2.91	493	69	145
20	2.02	0.01	0.69	0.48	3.89	446	68	144
21*	2.08	0.44	0.90	0.48	5.25	427‡	76	160
22*	3.03	0.43	0.74	0.50	0.95	519‡	78	188
23*	2.97	1.84	0.74	0.51	1.96	486‡	77	196

* Mottled fracture in ¾-inch bar.
** ¾-inch bars.
† Not determined.
‡ Hardness numbers of white areas.

sistance is gained by adding copper to white or chilled iron in excess of its limits of solid solubility in these alloys. Whether the presence of less copper is of value is now being investigated by the authors. In alloys of sufficiently high carbon content the graphitizing effect of this element may so lower their wear resistance as to put them out of the running in any abrasion test.

29. The microstructure of the copper-bearing irons was similar to that of the copper-free alloys. A comparison of Fig. 4A (the structure of a 2 per cent carbon, copper-free iron at a magnification of 200 diameters) with Fig. 5B (the structure of an iron of otherwise similar analysis but containing 5.25 per cent of copper at a magnification of 200 diameters) will emphasize this fact. The copper-bearing irons were found to be less resistant to attack by the etching reagents employed than were the alloys free from copper.

TESTS ON BALLS—EFFECT OF PHOSPHORUS

30. A series of twelve alloys was prepared for the purpose of investigating the effect of phosphorus on the wear resistance of

white iron. Phosphorus was introduced into the melts in the form of ferro-phosphorus (24 per cent P). The compositions of the alloys, as determined by chemical analysis, are given in Table 4.

Table 4

Alloys Used in Tests to Determine Effects of Phosphorus on Wear of Sand-Cast Balls.

Alloy No.	T.C. (%)	G.C. (%)	Si. (%)	Mn. (%)	P. (%)	Cu. (%)	Average Vickers Hardness Number	Wear Numbers	
24	2.04	N.D.*	0.71	0.53	0.51	....	433	58	135
25	2.02	N.D.	0.71	0.50	0.98	....	434	59	150
26	2.02	N.D.	1.22	0.49	0.55	....	449	58	139
27	1.96	N.D.	1.26	0.54	1.01	....	459	60	144
28	2.55	N.D.	0.73	0.39	0.48	....	466	63	139
29	2.58	N.D.	0.75	0.41	0.98	....	533	66	142
30	2.51	0.02	0.71	0.61	2.12	....	560	91	185
31	2.53	0.61**	1.21	0.51	0.50	....	430	77	150
32	2.54	0.14**	1.22	0.50	1.01	....	499	77	152
33	2.71	0.43**	1.28	0.48	1.89	....	564	63	140
34	3.10	0.10	0.67	0.48	0.57	....	511	62	136
35	3.08	0.99	1.15	0.50	0.43	....	424	74	153
36†	3.49	N.D.	0.73	0.26	0.25	....	500	71	167
14	2.08	N.D.	1.17	0.48	....	....	399	57	125
2	2.51	0.03	1.13	0.47	....	....	458	59	128
15	3.02	N.D.	0.75	0.55	....	....	511	62	136
17	2.00	0.03	0.75	0.48	....	1.00	422	59	124

* Not determined. ** See para. 34. †Commercial balls.

31. The only variables over which no control was held in this series of tests were the jars. By this is meant that duplicate balls of alloys 24 to 27, together with one commercial ball (alloy 36), were tested in *one* jar, duplicate balls of alloys 28 to 31, together with one commercial ball, were tested in *another* jar, while duplicate balls of alloys 32 to 25, together with one commercial ball, were tested in *yet another* jar. The grade and nature of the silicon carbide used in all three jars were as nearly the same as possible—all the carbide came from the same bag. This carbide was also used in another jar into which duplicate balls of four of the alloys which had been already tested, together with one commercial ball, were charged. In view of all this, it is believed that the results

quoted in Table 4 may, with some justification, be compared among themselves.

32. A comparison may also be made between the results of the tests on the alloys referred to in Table 4, which had already been tested, and those previously obtained on the same alloys. From Table 3, therefore, the items of Table 5 have been extracted. The lower and higher wear numbers of these alloys fall in the orders 65, 71, and 67, and 132, 152, and 140, respectively—or in the ratios 1 : 1.09 : 1.03, and 1 : 1.15 : 1.06, respectively.

Table 5

Alloy No.	T.C. (%)	G.C. (%)	Si. (%)	Mn. (%)	Cu. (%)	Average Vickers Hardness Number	Wear Numbers	
14	2.08	N.D.*	1.17	0.48	....	399	65	132
15	3.02	N.D.	0.75	0.55	....	511	71	152
17	2.00	0.03	0.75	0.48	1.00	422	67	140

* Not determined.

In the tests referred to in Table 4 the ratios for balls of these same alloys are as follows:

Lower	1	:	1.09	:	1.03
Higher	1	:	1.09	:	0.99

The ratios of the lower wear numbers happen to parallel one another to perfection; those of the higher wear numbers do not fall into such good order. However, they lie at about the limits of experimental error for these tests as a whole, and well within them in so far as the lower-carbon alloys are concerned.

33. The results quoted in Table 4 confirm that the wear resistance of white cast iron varies inversely with its carbon content, other things being equal. Maximum wear resistance is probably attained in alloys which at room temperature consist entirely of primaustenoid.[2]

[2] H. M. Howe, on page 68 (para. 80) of "The Metallography of Steel and Cast Iron," says: "This special complex or conglomerate of pearlite with pro-eutectoid cementite in this 6.4 : 1 ratio, or 14 per cent of pro-eutectoid cementite to 86 per cent of pearlite, of which unhardened steel of 1.70 per cent of carbon consists, plays a part of such importance in the structure of the eutectiferous group that we may give it the special name 'austenoid of 1.70 per cent of carbon,' or '1.70 per cent austenoid,' recalling the fact that it is the product of the metamorphosis or transformation in cooling of the austenite of 1.70 per cent carbon which forms in the solidification of all alloys containing more than 1.70 per cent of carbon. The limiting adjective 1.70 per cent need be used only when austenoid of this specific carbon content needs to be distinguished from austenoid poorer in carbon." Later, on page 69 (para. 83), he says: ". . . austenoid not thus honeycombed as part of the eutectic may be called '1.70 per cent primaustenoid,' because it is derived, with but little change of outline from the transformation of the primary austenite of 1.70 per cent of carbon in cooling. . . ."

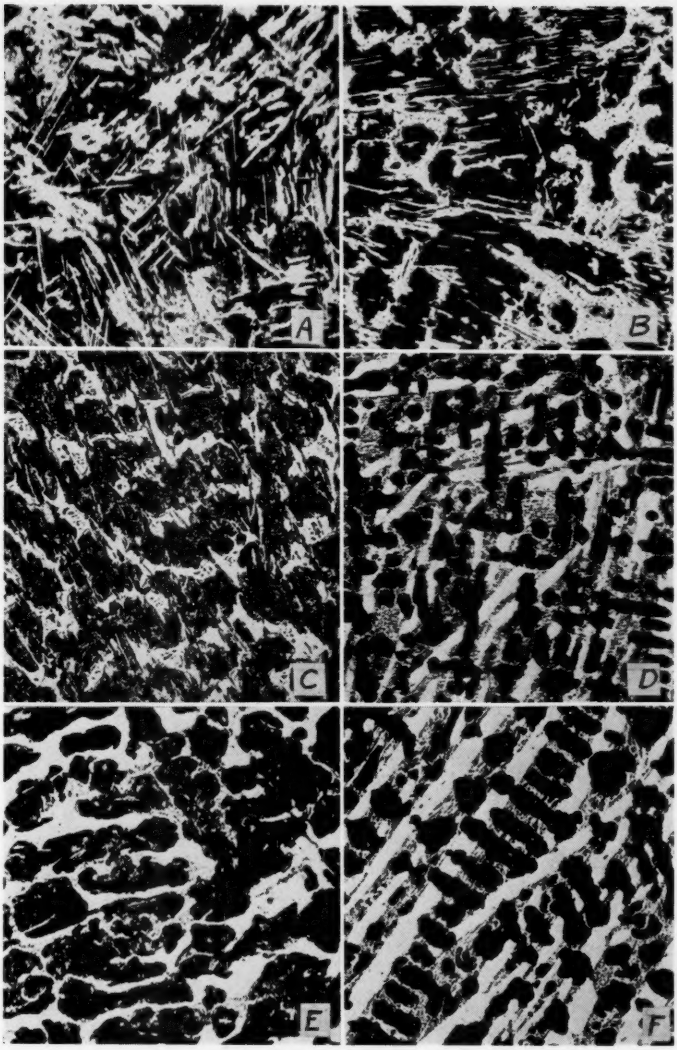

Fig. 4—(A) and (B) Showing Similarity of Structure of Copper Free and Copper-Bearing Alloys of Otherwise Similar Analysis. (A) 2.05 Per Cent C. (B) 2.08 Per Cent C, 5.2 Per Cent Cu.—X200.

(C) 2.47 Per Cent C, Low Phosphorus Iron (Ball); Compare with (D) and Note High Primaustenoid Content and Absence of Steadite.—X200.

(D) 2.51 Per Cent C, 212 Per Cent P Iron Ball, Compare with (C) and Note Low Primaustenoid and Presence of Steadite and Compare with (F) and Note Finer Structure of Ball.—X200.

(E) 2.58 Per Cent C, 0.98 Per Cent P, Iron (Bar); Compare with (F) and Note High Primaustenoid Content and Low Steadite.—X200.

(F) 2.51 Per Cent C, 2.12 Per Cent P Iron (Bar); Compare with (E) and Note Low Primaustenoid Content and High Steadite Content, and Compare with (D) and Note Coarser Structure of Bar.—X200. (These Micrographs Reduced ⅓ in Printing.) (All × 200.)

34. In so far as phosphorus is concerned, the same results indicate that in low-carbon irons (2 per cent total carbon) its effect is small, its tendency, however, being to reduce the wear resistance of these alloys. Phosphorus, other things being equal, reduces the proportion of primaustenoid in white cast irons. This effect is clearly seen in Figs. 4C and D, which show the structures (Fig. 4C) of a ball containing 2.47 per cent, total carbon, 0.66 per cent silicon, 0.47 per cent manganese, and less than 0.05 per cent phosphorus, and (Fig. 4D) of a ball (alloy 30) containing 2.51 per cent total carbon, 0.71 per cent silicon, 0.61 per cent manganese, and 2.12 per cent phosphorus.

35. In the 2½ per cent carbon alloys of the lower silicon

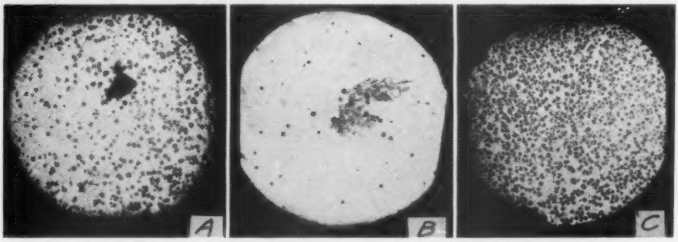

FIG. 5—(A) 2.53 PER CENT C, 0.50 PER CENT P (BALL); (B) 2.54 PER CENT C, 1.01 PER CENT P BALL; (C) 2.71 PER CENT C, 1.89 PER CENT P BALL—TO SHOW AMOUNTS AND TYPES OF GRAPHITIZATION IN THESE ALLOYS. (MAGNIFICATION APPROX. 1½ ACTUAL SIZE.)

content (¾ per cent), increased phosphorus lowered their wear resistance. In this series, however, wear increased surprisingly when the phosphorus was raised from 0.98 to 2.12 per cent (see Table 4). This changed behaviour was doubtless caused by the marked structural change which resulted in turn from the increase in phosphorus. A comparison of the structures of these alloys (¾ inch-diameter bars) may be made by reference to Figs. 4E and F, the former being that of the 0.98 per cent alloy (No. 29), the latter being that of the 2.12 per cent alloy (No. 30). The alloy of lower phosphorus content will be seen to have contained but traces of steadite, whereas that of the higher phosphorus content contained quite large proportions of this constituent, the friability of which, the authors believe, accounted for the alloy's readiness to wear. Comparison of Figs. 4D and 4F will show the difference in structure between a ¾ inch, sand-cast bar and a 1 inch, sand-cast ball, both of alloy 30.

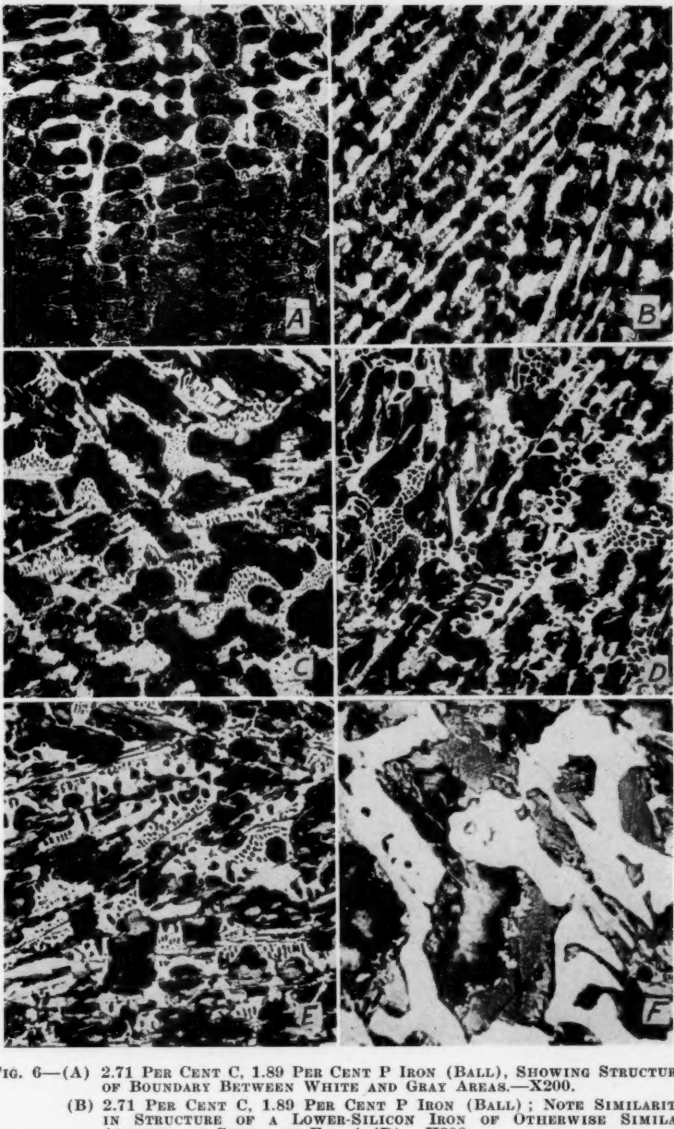

FIG. 6—(A) 2.71 PER CENT C, 1.89 PER CENT P IRON (BALL), SHOWING STRUCTURE OF BOUNDARY BETWEEN WHITE AND GRAY AREAS.—X200.

(B) 2.71 PER CENT C, 1.89 PER CENT P IRON (BALL); NOTE SIMILARITY IN STRUCTURE OF A LOWER-SILICON IRON OF OTHERWISE SIMILAR ANALYSIS AS SHOWN IN FIG. 4 (D).—X200.

(C) 2.91 PER CENT C, 0.28 PER CENT MN, COMPARE WITH (D) AND (E) FOR PURPOSE OF SHOWING HOW LITTLE MN. AFFECTS THE PRIMAUSTENOID CONTENT OF WHITE CAST IRON.—X200.

(D) 2.95 PER CENT C, 0.97 PER CENT MN.—X200.

(E) 3.11 PER CENT C, 2.79 PER CENT MN.—X200.

(F) 3.01 PER CENT C, 6.56 PER CENT MN. IRON.—X750. SEE PARAGRAPH 45.

36. The effect of phosphorus on the wear of the $2\frac{1}{2}$ per cent carbon alloys of the higher silicon content ($1\frac{1}{2}$ per cent) is notable, even though the irons were not white, the wear numbers of the high-phosphorus alloy being quite out of line with those of the others in this group. It should be noted here that the figures quoted in Table 4 for the graphitic carbon content of these alloys (Nos. 31, 32, and 33) can scarcely be considered as representative of the alloys as a whole. Graphitic carbon was present in these alloys in two forms, (1) as massive carbon and (2) as eutectic carbon. What is meant by these terms will be understood on reference to Figs. 5 and 6A. In Fig. 5 are shown the etched sections of three balls of compositions 31, 32, and 33, respectively. In two of these (A and B) quite large areas of massive *graphite* can be seen; the other section (C) contains no such graphite. Distributed irregularly through all the sections are round areas of gray iron, which contain *eutectic graphite.* The photomicrograph, Fig. 6A, shows the boundary between such an area and the white matrix in which it lies. Now, the amount of carbon present within each of the gray spheres in castings (bars or balls) of these alloys is likely to be about the same. A study of Fig. 5 thus leads to the opinion that the carbon content, *due to mottling,* of alloy 31 is greater than that of alloy 32, but less than that of alloy 33, and that the high apparent carbon content (as determined by chemical analysis) of alloy 32, viz., 0.61 per cent, is due to massive graphite which happened to be present in the material removed for analysis. Had this material been removed from another section of the casting, a different value for graphitic carbon content might have been obtained.

37. The high wear resistance of alloy 33 is somewhat surprising but can be explained. The structures of the white areas in castings of alloys 31 to 33, whether bars or balls, were practically identical with those of castings in alloys 28 to 30. In the alloys (both series) of equal phosphorus content the proportions of primaustenoid, ledeburite, and steadite were practically the same, as may be seen if comparison be made, for example, between Figs. 4D and 6B, which are structures chosen at random in balls of alloys 30 and 33, respectively. The gray portions in castings of alloy 33 differed slightly in structure from those in castings of alloys 31 and 32, in that they contained traces of undecomposed ledeburite. If the undecomposed ledeburite be left out of account, it can be said that the structures of the gray portions of alloy 10

consisted of primaustenoid and pseudo-binary eutectic—to use the term coined by Künkele.[3]

38. In other tests (Tables 2 and 3) the mottled irons wore more readily than the white. It was to be expected, therefore, that the mottled irons 31, 32, and 33 would wear more readily than the white irons 28, 29, and 30, as indeed they did, with the outstanding exception of alloy 33. The structures of neither the white nor the gray portions of castings of this alloy can be used to account for its peculiar behaviour. There remains the possibility that the primaustenoid in the gray portions of alloy 33 is exceptionally resistant to wear. Such exceptional resistance can be due only to the presence in the primaustenoid of hardening elements such, for example, as silicon, etc. These elements would be in solution in both the body-centered iron and the iron carbide present in the pearlite, as well as in the pro-eutectoid iron carbide.

39. How can such elements find their way into the primaustenoid? It is suggested that, during the last stages of freezing of these alloys, the dendrites of austenite in the ultimately gray portions of the castings are surrounded by liquid high in carbon, containing appreciable portions of silicon. On reaching the eutectic temperature for the *stable* system, graphite forms (possibly as a result of the decomposition of iron carbide), thus releasing, for solution in the neighboring dendrites of austenite, such silicon as would be retained in solid solution in the iron carbide, were *metastability* established. On cooling to room temperature the austenite will change to primaustenoid, which, however, will still retain in solid solution such silicon as has entered at the stable eutectic temperature. It is suggested that it is the presence of such dissolved silicon in the primaustenoid which accounts, not only for the remarkable behaviour of alloy 33, but for the comparatively high wear resistance of the 3½ per cent carbon alloys of high silicon content referred to in Table 2 and paragraph 25.

Tests on Balls—Effects of High Manganese and of Manganese Plus Sulphur

40. A series of six alloys was prepared for the purpose of investigating the effect of high proportions of manganese on the wear resistance of white iron. At the same time a series of three alloys was made to test out the effect of sulphur. The composi-

[3] Mitt. aus dem Kaiser-Wilhelm-Institut für Eisenforschung, 1930, 13, (4), pp. 23-31.

tions of these alloys, as determined by chemical analysis, were as given in Table 6.

41. These tests provide further material with which to prove the value of the ball-mill type of test. Comparison may be made here between the results of the tests on the alloys listed in Table 6 and others already obtained on the same or similar materials. Reference may again be made to Table 5. As pointed out in paragraph 32, the ratios of the wear numbers for these alloys are 1 : 1.09 : 1.03 and 1 : 1.15 : 1.06, respectively. In the tests referred to in Table 6, the ratios for balls of the same or similar alloys[4] are as follows:

Lower wear number — 1 : 1.34 : 1.03
Higher wear numbers — 1 : 1.35 : 1.06

Table 6

ALLOYS USED IN TESTS TO DETERMINE EFFECTS OF MN AND MNS ON WEAR OF SAND-CAST BALLS.

Alloy No.	T.C. (%)	G.C. (%)	Si. (%)	Mn. (%)	S. (%)	Cu. (%)	P. (%)	Average Vickers Hardness Number	Wear Numbers	
37*	1.96	0.24	1.16	0.51	....	....	....	363	69	141
38‡	2.45	N.D.†	1.20	0.58	....	....	....	415	70	146
15	3.02	N.D.	0.75	0.55	....	....	....	511	94	189
17	2.00	0.03	0.75	0.48	....	1.00	....	422	72	146
39	2.04	0.05	1.22	2.71	....	....	....	444	70	143
40	2.58	N.D.	1.27	2.50	....	....	....	466	75	160
41	3.11	N.D.	1.30	2.79	....	....	....	548	99	195
42	2.10	N.D.	1.28	6.20	....	....	....	569	77	168
43	2.50	N.D.	1.28	6.13	....	....	....	555	75	160
44	3.01	N.D.	1.27	6.56	....	....	....	639	84	177
45	2.43	N.D.	1.23	0.98	0.14	....	....	432	77	159
46	2.50	0.11	1.31	0.91	0.37	....	....	444	79	164
47	2.50	N.D.	1.20	0.92	0.58	....	....	419	84	177
36**	3.49	N.D.	0.73	0.26	....	....	0.25	500	90	203

* Corresponding to alloy 14.
‡ Corresponding to alloy 2.
** Commercial balls.
† Not determined.

[4] In Table 6 an alloy containing 1.96 per cent carbon is used in comparison with that in Table 3, which contained 2.08 per cent carbon.

For the three sets of tests (Tables 3, 4, and 6) the following ratios apply:

Lower wear numbers —	Table	3—	1	: 1.09	: 1.03
	"	4—	1	: 1.09	: 1.03
	"	6—	1	: 1.34	: 1.03
Higher wear numbers—	Table	3—	1	: 1.15	: 1.06
	"	4—	1	: 1.09	: 0.99
	"	6—	1	: 1.35	: 1.06

From the foregoing it will be appreciated that the results obtained with relatively low-carbon alloys (2 per cent) were distinctly more consistent than those obtained with relatively high-carbon alloys (3 per cent)—alloys containing relatively large proportions of eutectic.

42. The results quoted in Table 6 appear to emphasize once again the preponderant effect of carbon upon the abrasion of white iron balls. Further, they show that to increase the manganese in these alloys is not to improve their resistance to wear.

43. Within the limits here dealt with, manganese has apparently no effect on the proportions of primaustenoid and eutectic in white iron, as may be seen in Figs 6C, D and E, which are photomicrographs of three alloys, otherwise very similar, but containing 0.28, 0.97, and 2.79 per cent of manganese, respectively. Such effects upon wear as are produced by this element must therefore be associated with its effect upon the transformation of face-centered iron to body-centered iron.

44. The entire series of 2¾ per cent manganese alloys (Nos. 39, 40, and 41) was characterized by a troostitic matrix in which ledeburite was embedded. Small amounts of a brown-etching constituent were present with the troostite, these increasing with carbon content.

45. The entire series of 6¼ per cent manganese alloys (Nos. 42, 43, and 44) was characterized by a matrix of a brown-etching constituent in which ledeburite was embedded. Small amounts of what appeared to be austenite were present with the brown-etching constituent, these increasing with carbon content. The austenite was fringed with what appeared to be martensite. Between the fringe of martensite and the brown-etching constituent small crystals of iron carbide were frequently found. Fig. 6F shows the structure of a typical section of alloy 44 at a magnification of 750 diameters.

46. It is of interest to compare the wear resistance of alloys

16 and 19, both 3 per cent carbon alloys—one having a troostitic matrix containing martensite, the other a martensitic matrix containing austenite; the latter was superior to the former. The question whether this superiority was due to the presence of austenite, however, can be answered only by tests on balls consisting of austenitic primaustenoid plus ledeburite, of martensitic primaustenoid plus ledeburite, and of pearlitic or troostitic primaustenoid plus ledeburite.

47. Turning now to the sulphur-bearing alloys, it is noteworthy that during the early stages of test their wear resistance was phenomenal. However, once the apparently hard, sulphide-free skin was removed from the balls, they lost weight quite rapidly, their surfaces becoming honeycombed with pits. The numbers of these pits made it possible to distinguish readily between balls of different sulphur content. During the last stages of test, when the superficial manganese sulphide had been removed from the balls, the losses of weight fell to those of ordinary $2\frac{1}{2}$ per cent carbon iron. The rate of wear on these balls, however, was quite irregular, due in all probability to the bodily removal of inclusions of manganese sulphide from time to time.

CONCLUSIONS

(1.) Given a suitable abrading medium, the ball mill can be used to measure the wear resistance of white cast iron.

(2.) The higher the carbon content or, more generally, the lower the primaustenoid content of white cast iron, the less consistent are the results of wear tests on cast balls made from these materials.

(3.) The higher the carbon content of white cast iron, other things being equal, the lower is its wear resistance under the conditions of test described.

(4.) Variations in amounts of manganese up to about 1 per cent are practically without effect upon the wear resistance of white cast iron. No benefits accrue from adding up to 6 per cent of manganese to white cast iron containing ledeburite.

(5.) Increase of silicon from about $\frac{3}{4}$ per cent to about $1\frac{1}{2}$ per cent has little or no effect on the wear resistance of white cast iron but results in a remarkable increase in that of mottled irons. It is suggested that this increase in wear resistance is due to the solution in austenite, at the stable eutectic temperature, of

silicon which is made available as a result of dissociation of eutectic iron carbide and the consequent formation of graphite, but which would be retained in solid solution in the eutectic iron carbide, were *metastability* established.

(6.) Sulphur is deleterious in its effect on the wear resistance of white cast iron.

Acknowledgments

The authors desire to acknowledge the interest shown in this work and the encouragement given them by Dr. H. B. Speakman, director of the Ontario Research Foundation, and the help afforded them by Messrs. Desmond Hunter and Edwin Nugent in the preparation of the numerous alloys examined.

DISCUSSION

H. Deane:[1] Have the authors any explanation as to why the sand cast bars wore better than the chilled cast bars? I have reason to agree with the authors but do not have any explanation.

Mr. Gordon: It seemed to be the rule that the chilled cast bars were less resistant to wear than the sand cast bars. Bars with lower hardness numbers had greater resistance to wear than those of high hardness. This was true whether the variations in hardness were due to the composition of the alloys or to the method of casting. It is possible to account for the behaviour in the former case, but we are unable at present to offer a satisfactory explanation of the latter.

H. Bornstein:[2] I believe that the results of wear tests should be judged very, very carefully. We have had occasion to make wear tests from time to time and the only laboratory tests that we have been able to find that correlate at all with service tests are the Brinell abrasion tests, which are also described by Mr. Rosenberg of the Bureau of Standards in one of the A.S.T.M. papers. We have tried in the past to make ball tests. They are simpler but we have not been able to get results which correlate at all with service conditions. So I think it is necessary to use these results with caution if you expect the results to correlate at all with service conditions which are in any way different from the conditions of the test itself. That is, if you were going to use these results simply for service in a ball mill, it may be all right. If you are going to use it for another type of service, it may not be all right.

Another thing we have found from our experience is that the higher carbon alloys wear better than the lower carbon alloys. We have had experience in trying to use some parts made from a malleable white iron with about 2.40 per cent total carbon, and we have found those

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[2] Chief Metallurgist, Deere & Co., Moline, Ill.

parts do not wear nearly as well as parts made from metal with about 3.50 per cent total carbon.

MR. GORDON: Mr. Bornstein rightly stresses the danger of attempting to apply the results of ball mill tests to other wear conditions. This point was fully recognized by the authors and was indicated in the earlier part of the paper.

J. S. VANICK:[3] I believe a paper such as Director Ellis and his co-workers have given us is capable of being developed into quite a useful pilot test on wearing resistance of white irons. I would hesitate to plunge into the intricate problems of ball milling directly from the results obtained in a test of this kind. Some of the reasons for that lie in the apparently different or directly opposite results obtained in every-day production of relatively high carbon versus low carbon ball materials. Of course, none of the grinding balls in use today drop down to this 2 per cent carbon range. And when they do get that low, I believe it would be a mighty handy thing to match them with a steel ball, which would also be practically 100 per cent austenitic in structure and would contain relatively little iron carbide.

One of the difficulties in measuring the wear of a high carbon material, such as in those irons with carbons running over 2.50 per cent, occurs in the spalling of the surfaces of these ball materials which the authors somewhat indicate by saying that the high carbon balls pitted. Those pits might have been very small spalls chipping out of the skin along the carbide boundaries. And some indication as to whether that was actually occurring might have been obtained by screening the output of the mill and endeavoring to measure the solid iron particles in some way as distinct from the carborundum or whatever material was being put through the mill. That might have to be a gravity separation of some kind which would definitely indicate solid iron as against dissolved or worn away iron.

The test, I believe, has possibilities of being developed into a very fine means for distinguishing the differences in performance for various degrees of carbide plus prima-austenite percentage contents in the structure. That is, a high carbon material, running say nearly 4 per cent carbon, will contain approximately, I believe, 40 per cent or so of carbide and 60 per cent of matrix or austenite. By cutting that down to 2 per cent carbon, the carbide component is practically wiped out. Experiments upon white iron of varying carbon content might be made as a fundamental wear test (for the conditions prevailing in this particular mill) and a very good index of the relation between structure and wear might thus be developed.

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[3] International Nickel Co., New York, N. Y.

Factors Affecting the Structure and Properties of Gray Cast Iron

By A. Di Giulio* and A. E. White†

Abstract

In the research on which this thesis is based, the effect of superheating cast iron of the unalloyed automotive-cylinder type was investigated by heating the metal to 3110 degrees Fahr. The beneficial effects of superheating were apparent at temperatures in the neighborhood of 2700 degrees Fahr., and increased with temperature up to a maximum at about 3040 degrees Fahr. The effect of pouring temperature on various cast irons also was investigated. An optimum range for pouring was established between 2680 and 2850 degrees Fahr. Better physical properties obtained through superheating and by pouring at the proper temperature are ascribed to a refinement of the graphite flakes. Specifically, the improvement in physical properties is due to the fact that, under proper conditions of melting and casting, the graphite flakes of the material of the charge are entirely dissolved. Evidence is furnished which proves that graphite will not all pass into solution at the eutectic temperature, but will persist as such in the melt, as revealed by quenching molten cast iron in water.

EFFECT OF SUPERHEATING AND POURING TEMPERATURE

1. During recent years, gray cast iron has been the subject of many investigations which have dealt mostly with the study of the effects that the chemical composition has on the physical properties. The investigations here reported deal primarily with the study of the effects of superheating and pouring temperatures on the structure and properties of gray cast iron.

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* This paper is an abstract of a thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Science in Metallurgy at the University of Michigan.

* Superior numbers refer to bibliography at the end of this paper.

Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

REVIEW OF THE LITERATURE

2. The influence of the melting temperature on cast iron was first brought out in 1913 by G. Hailstone,[1*] who called attention to the fact that the quality of cast iron could be improved by increasing the temperature of the metal above the temperatures in use at the time. Research on this subject received no further impetus until E. Piwowarsky,[2] in studying the methods of production of high-test cast iron from data gathered from many foundries in Germany and Holland, stated that by melting irons at a temperature close to 2900 degrees Fahr., the tensile and transverse strength increased 15 to 18 per cent. A serious objection to Piwowarsky's work is the fact that no consideration was taken of the pouring temperature, and the chemical composition and structure of the irons used, varied considerably. It is obvious that comparison between structurally different irons cannot be made.

3. Following Piwowarsky's work, Hanemann[3] stated that graphite does not all go into solution, and that in the process of melting, centers of crystallization remain. A temperature may be reached at which graphite may be totally melted; hence the beginning of rapid crystallization is removed and consequently, finer graphite flakes are formed which result in an increase in tensile strength. P. Bardenheuer[4] believes with Piwowarsky that a further important effect of superheating is the elimination of gases, which makes a denser structure possible. None of these investigators took into consideration the effect of pouring temperature on the physical properties and structure of gray cast iron.

4. The first investigator to differentiate between superheating temperature and casting temperature was Tanimura.[5] He used a noble-metal couple to measure these temperatures, differentiated between superheating and pouring temperature, and kept the casting temperature constant at 1250 degrees Cent. (2282 degrees Fahr.). Tanimura quenched 50, 25, and 10-gram samples in mercury. His conclusions were: "It appears that cast iron, melted at high temperatures, solidifies with indirect graphitization, while a cast iron, melted at low temperatures, solidifies with direct crystallization of graphite."

5. According to H. Pinsl,[6] superheating is not the only factor to affect the physical properties of cast iron. According to this investigator, pouring temperature is just as important.

He believes that an optimum pouring temperature, independent of the superheating temperature, which gives the best physical properties, exists for each iron. In this respect, this work is in contradiction of the work of A. Koch,[7] who recommends that, to obtain high physical properties, the pouring temperature should be as low as possible. The lowest temperature is the liquidus point for the particular composition of the iron.

6. The most recent work on properties of gray iron has been carried out by Saeger and Ash[8] of the Bureau of Standards. They correlate maximum temperature of heating with other factors, such as:

(1) Running qualities, which are not affected by superheating temperature.

(2) Physical properties, which are increased as superheating increases (the strength of the irons), according to the cross sectional area of the test bar.

(3) Microstructure, which is affected as evidenced by the fact that low-strength irons are associated with relatively straight graphite flakes and coarse pearlite, whereas high-strength irons are associated with relatively small graphite flakes in a matrix of fine pearlite or sorbite.

Summary of the Literature

7. Review of the literature shows that:

(1) Opinion regarding the presence of graphite in molten iron is divided.

(2) Superheating is known to improve the properties of gray iron; however, not enough data is available to be able to predict the magnitude of its effect.

(3) The effect of pouring temperature on physical properties has been little investigated.

(4) Methods used in measuring the temperatures leave much to be desired in the way of accuracy.

Experimental Procedure

8. In carrying out this research, the utmost care was exercised to reduce the effect of factors which might ordinarily invalidate results.

Temperature Measurements

9. At the beginning of this investigation, it was realized that great care was necessary to take accurate temperature meas-

urements. It was decided to use a noble-metal couple enclosed in suitable protection tubes.

10. The assembled couple was immersed 5-in. in the molten bath, and, although only 90 seconds were required for the couple to attain equilibrium, it was kept immersed for a total time of 4 minutes. In no case did any correction have to be made to the original calibration, and the accuracy of the readings is well within ± 10 degrees Cent.

Materials

11. In order not to introduce a variation in the hereditary characteristics of the cast iron to be used, a 3000-lb. melt was made in the cupola to serve as a base metal for all subsequent heats.

12. The charge consisted of pig iron, steel scrap, and foundry scrap. All of the metal was tapped into one ladle, stirred and cast into pigs, which were tumbled prior to being used as base material.

13. The analysis of this gray iron was as follows:

Element	Per Cent	Element	Per Cent	Element	Per Cent
T.C.	3.36	S.	0.118	O.	0.012
G.C.	2.76	P.	0.36	H.	0.00015
Si.	2.00	Mn.	0.48	N.	0.0045

14. This composition is close to the one recommended for unalloyed automobile cylinders, except for phosphorus. Attempts were made to take the temperature in the crucible of the cupola. Unfortunately, no refractory material in the form of tubes has yet been found which would withstand the action of the slag and the thermal stress due to the temperature gradient. The pouring temperature from the ladle was 2435 degrees Fahr. Standard test bars, 1.2-in. diameter, 21 in. long, were cast in dry-sand cores. Transverse specimens were broken between 18-in. supports, and the specimens for tensile strength were machined from the broken half of the transverse bars, according to A.S.T.M. Specifications A48-32 T.[9]

15. Physical properties, for the average of six samples, were as follows:

Tensile Strength, lb. per sq. in.	26,800
Transverse Strength, lb.	1915
Deflection, in.	0.290
Brinell Hardness	202

The hardness measurements were taken on a cylindrical sample ½-in. thick, one side of which was used to take hardness readings at the center. Two other readings were taken on the opposite side, close to the periphery.

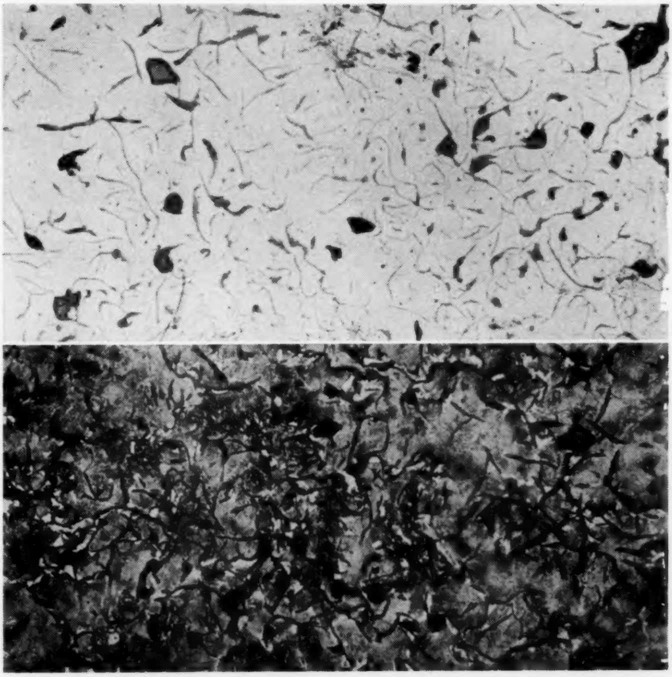


Fig. 1—Structure of Cupola Iron Used as Base Metals for All Subsequent Heats. Above—Unetched, x100. Below—Etched in 3 Per cent Nital, x100.

16. Fig. 1 shows the structure of the base iron at 100 diameters, unetched and etched.

Furnace

17. Melting was carried out in a 250-lb. capacity Detroit electric rocking type furnace. A "wash heat" was used to prevent any contamination from preceding runs. Temperature rise of the molten metal was measured with the thermocouple previously mentioned.

Casting Practice

18. Pouring temperature was measured just before pouring the metal into the molds. Molds of the vertical type were made with fine Michigan dune sand and baked in a core oven for 4 hours at 400 degrees Fahr. A pouring basin allowed the metal to flow into the two cavities. To prevent chilling of the lower end of the test bars, two baked sand plates, 1-in. thick, were placed at the bottom of the core.

EFFECT OF SUPERHEATING ON STRUCTURE AND PROPERTIES OF GRAY CAST IRON

19. The purpose of this series of experiments was to study the effect of the maximum temperature of heating on the size and distribution of the graphite flakes, and on the physical properties of gray iron.

20. To equalize the possible effect that the pouring temperature may exercise on the properties and structure, the temperature from which the metal was poured into the mold was kept constant at about 2700 degrees Fahr. Melts heated above 2700 degrees Fahr. were allowed to cool in the furnace.

21. The composition decided upon for this study was the one considered as typical of unalloyed automotive cylinder iron:[10]

T.C., per cent	Si., per cent	Mn., per cent	P., per cent	S. per cent
3.25	2.25	0.65	0.15	0.10

Results

22. Table 1 gives the history and the analysis of the irons.

Table 1

CHEMICAL COMPOSITION AND SUPERHEATING TEMPERATURE OF GRAY CAST IRONS

Heat No.	Superheating Temp., °F.	Pouring Temp., °F.	PER CENT COMPOSITION Total Carbon, %	Graphitic Carbon %	Combined Carbon, %	Si., %	P., %	S., %	Mn., %
1.	2570	2570	3.28	2.64	0.64	2.20	0.31	0.10	0.36
2.	2730	2730	3.34	2.57	0.77	2.26	....	....	....
3.	2855	2710	3.21	2.51	0.70	2.24	....	....	....
7.	2940	2715	3.30	2.51	0.79	2.30	0.34	0.09	0.44
4.	3035	2710	3.26	2.48	0.78	2.22	....	....	....
5.	3085	2730	3.26	2.53	0.73	2.31	....	....	....
6.	3110	2740	3.23	2.48	0.75	2.27	0.26	0.11	0.35

Table 2

Physical Properties of Superheated Gray Cast Iron Containing 3.25 Per Cent Total Carbon; 2.25 Per Cent Silicon

Heat No.	Transverse Strength, lb. Max.	Transverse Strength, lb. Min.	Transverse Strength, lb. Avg.	Mod. of Rupture, lb. per sq. in., Avg.	Deflection, In. Max.	Deflection, In. Min.	Deflection, In. Avg.	Tensile Strength lb. per sq. in. Max.	Tensile Strength lb. per sq. in. Min.	Tensile Strength lb. per sq. in. Avg.	Brinell Hardness, Avg.
1.	2300	1970	2140	56,750	0.33	0.28	0.31	36,600	36,340	36,470	194
2.	2190	2130	2160	57,250	0.31	0.30	0.30	37,840	36,030	37,000	205
3.	2480	2310	2410	63,900	0.37	0.35	0.36	39,870	39,085	39,420	202
4.	2680	2510	2585	68,250	0.38	0.33	0.35	43,600	40,900	42,140	212
5.	2110	1930	2040	54,000	0.23	0.20	0.21	35,730	33,525	34,400	269
6.	2270	2110	2192	58,000	0.30	0.27	0.28	36,060	24,980	35,500	241
7.	2560	2470	2520	66,800	0.37	0.36	0.36	41,300	40,300	40,975	205

Note: Values given were obtained from 8 specimens of each heat.

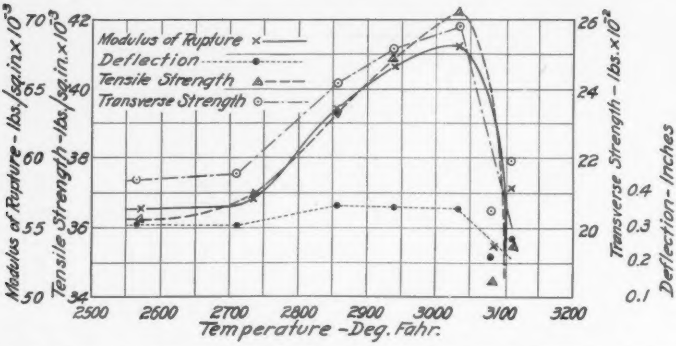


FIG. 2—EFFECT OF SUPERHEATING TEMPERATURE ON MODULUS OF RUPTURE, TENSILE STRENGTH, TRANSVERSE STRENGTH AND DEFLECTION.

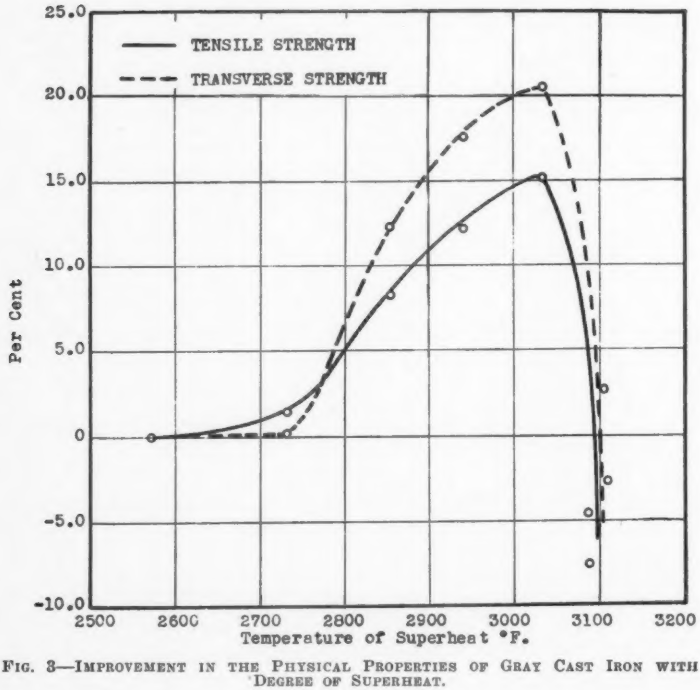


FIG. 3—IMPROVEMENT IN THE PHYSICAL PROPERTIES OF GRAY CAST IRON WITH DEGREE OF SUPERHEAT.

23. Eight standard arbitration bars were cast from each heat, and tensile specimens were machined from each of the transverse bars after breaking. Table 2 shows the maximum, minimum and average values obtained.

24. The values given in Table 2 are graphically represented in Fig. 2. Table 3 and Fig. 3 show the increase in tensile strength and modulus of rupture on a percentage basis, taking as reference the average value of the physical properties of Heat 1.

25. A photomicrographic study was made of the structure of representative samples of each iron, both in the etched and unetched condition. A polishing method, which will pull out the

Table 3

Improvement of Physical Properties Due to Superheating of Gray Cast Iron*

Heat No. Reference	Transverse Strength, lb. Avg.	Tensile Strength, lb. per sq. in., Avg.	Per Cent Improvement Transverse Strength	Tensile Strength
1.	2140	36,470	....	....
2.	2160	37,000	0.09	1.45
3.	2410	39,420	12.60	8.10
4.	2585	42,140	20.75	15.50
5.	2040	34,400	-4.50	-7.80
6.	2192	35,500	-2.43	-2.68
7.	2520	40,975	17.75	12.35

* Heat No. 1 taken as reference.

graphite, will cause each flake to appear much wider than it actually is, and thus may lead to faulty interpretations. Because it has proved very satisfactory, the dry method of polishing has been used in the preparation of all samples in this investigation.

Discussion of Results

26. Referring to Fig. 2, a similarity of trend is very noticeable. No beneficial effects are obtained by superheating cast iron until a temperature of around 2700 degrees Fahr. is reached, corresponding to iron 2 in the tables. As the superheating temperature is increased, the physical properties increase to a maximum at about 3035 degrees Fahr. Above this temperature, a sudden decrease of strength is accompanied by an increase in the hardness of the irons.

27. Irons 5 and 6, heated to 3085 and 3110 degrees Fahr. respectively, while establishing the upper limit of the beneficial temperature range, are devoid of great practical importance. Temperatures in the neighborhood of 3100 degrees Fahr. can be obtained only with electric furnaces and are uneconomical because

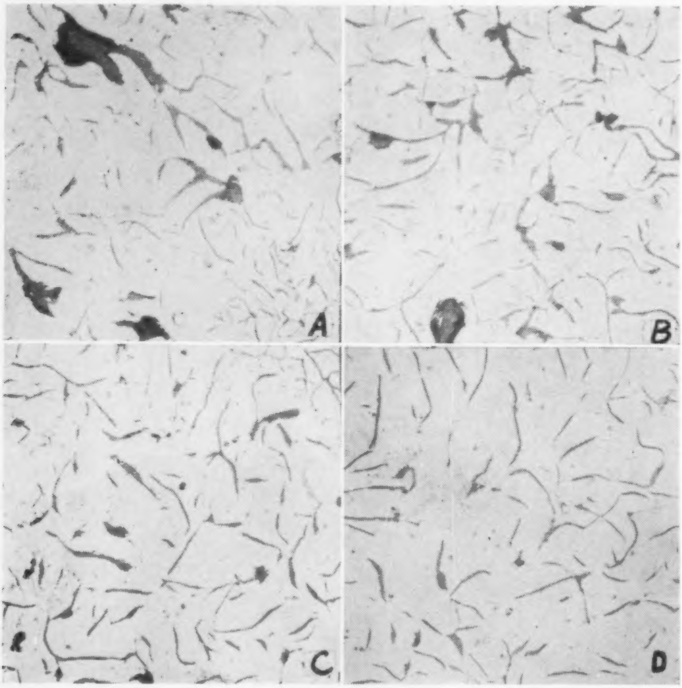


FIG. 4—A—IRON 1, SUPERHEATED TO 2570 DEGREES FAHR. AND POURED AT SAME TEMPERATURE, UNETCHED, x100. B—IRON 2, SUPERHEATED TO 2730 DEGREES FAHR. AND POURED AT THE SAME TEMPERATURE, UNETCHED, x100. C—IRON 3, SUPERHEATED TO 2855 DEGREES FAHR. AND POURED AT 2710 DEGREES FAHR., UNETCHED, x100. D—IRON 7, SUPERHEATED TO 2940 DEGREES FAHR. AND POURED AT 2715 DEGREES FAHR., UNETCHED, x100.

of the greater power and electrode consumption. Furthermore, the life of any furnace lining could not be expected to be very great at these extreme temperatures. For these reasons, attempts to obtain more data in this range of temperatures were abandoned.

28. Various investigators have mentioned the existence of an optimum superheating temperature, notably Hatfield[11] and

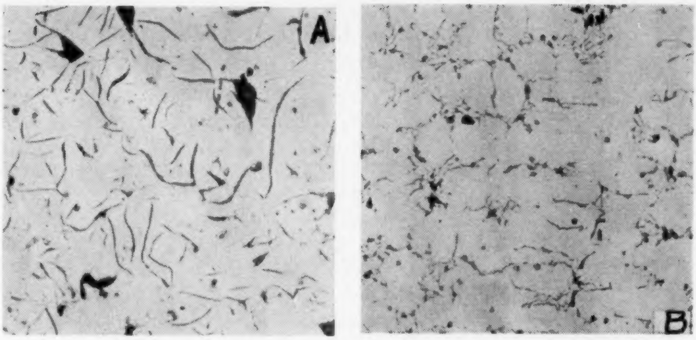


Fig. 5-A—Iron 4, Superheated to 3035 Degrees Fahr. and Poured at 2710 Degrees Fahr., Unetched, x100. B—Iron 5, Superheated to 3085 Degrees Fahr. and Poured at 2730 Degrees. Fahr., Unetched, x100.

Piwowarsky[12]. Saeger and Ash[8] have presented their results, although they have not carried on their work at temperatures above 3090 degrees Fahr. In their results, the decrease in physical properties is not as pronounced as it is in the present investigation. It should be noted that Saeger and Ash measured temperatures with an optical pyrometer.

29. The micrographic study, Figs. 4, 5 and 6, shows that the decrease in graphite size reaches a maximum at about 3035 degrees Fahr. in iron 4. Above this temperature, a different type of graphite appears. Figs. 5-B and 6 show that the large flakes common in cast iron are not present, and that the graphite is grouped in such a way as to outline a dendritic pattern.

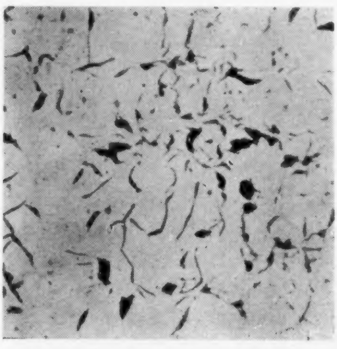


Fig. 6—Iron 6, Superheated to 3110 Degrees Fahr. and Poured at 2740 Degrees Fahr., Unetched, x100.

30. The graphite flakes of iron 4, superheated to 3035 degrees Fahr., (Fig. 5-A) are finer than those of iron 2, which was superheated to 2730 degrees Fahr. (Fig. 4-B). Since the composition of the irons is the same, it is logical to assume that during the graphitization of iron 4, more graphite crystallization nuclei were

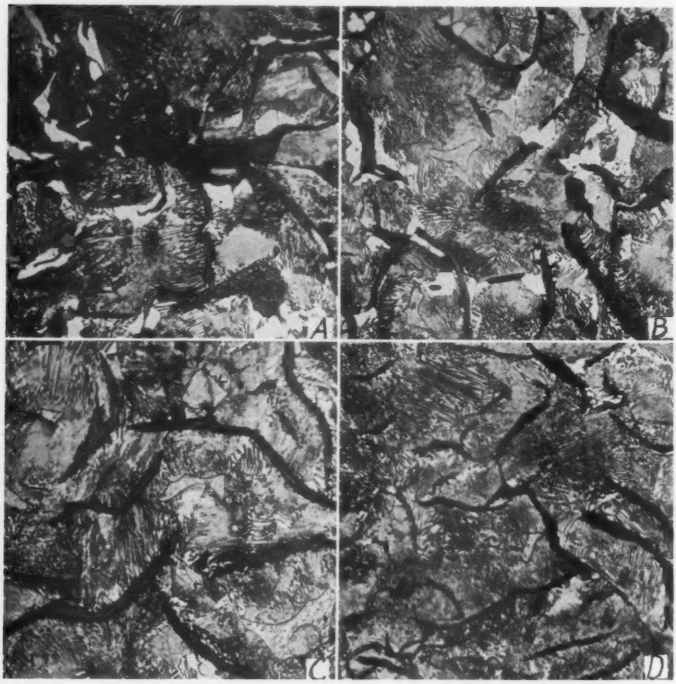


FIG. 7—A—SAME AS FIG. 4-A, ETCHED, x500. B—SAME AS FIG. 4-B, ETCHED, x500. C—SAME AS FIG. 4-D, ETCHED, x500. D—SAME AS FIG. 5-A, ETCHED, x500. (ALL MICROGRAPHS REDUCED ⅓ IN PRINTING.)

present upon which the graphite could deposit. In other words, this leads to the belief that the higher superheating temperature has brought out a greater number of nuclei, probably more uniformly dispersed throughout the mass, upon which carbon has deposited in the form of graphite. The question now arises as to whether the greater number of nuclei in highly heated irons is present in the iron at lower temperature or whether it is the result of the higher temperature.

31. If it is assumed with Honda, Murakami, and others, that no graphite exists in the molten iron, and that all the graphite in cast iron is the product of decomposition of cementite, it is hard to conceive that the superheating temperature can affect this transformation in such a way as to produce finer graphite flakes. A satisfactory explanation must, therefore, be sought.

32. Quantitative measurements of the actual number of graphite flakes, although attempted, had to be abandoned, because it was impossible to determine where one flake began and another ended, due to the examination being in one plane.

33. In this research, it will be observed from Figs. 7 and 8,

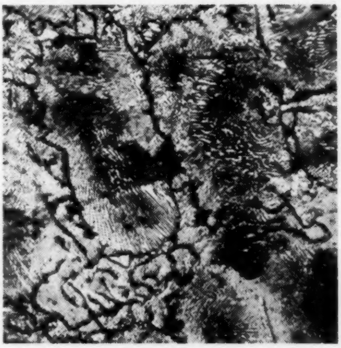


Fig. 8—Same as Fig. 5-B Etched, x500. (Reduced ⅓ in Printing.)

that all the irons are structurally the same; that is, the matrix is mostly pearlitic in all of them, with very little ferrite appearing in spots around the graphite flakes of irons 1 and 2. No evidence of free carbides could be found in any of the irons after etching with Murakami's reagent.

34. As has been pointed out, the graphite in irons 5 and 6 not only shows the small curved flakes, but also shows, what seems to be more important, a definite dendritic pattern. It is this special agglomeration which, in the author's opinion, is responsible for the low strength of these irons. A fracture once started, by following one of the axes of the dendritic pattern, may travel almost continuously through the graphite without ever crossing much of the matrix.

35. The results of the experiments on the superheating of cast iron show that the increase in physical properties between the temperatures of 2700 and 3035 degrees Fahr. is due to a

refinement of the graphite flakes, and that low properties of the highly superheated irons are caused by the effective breaking up of the matrix due to the dendritic pattern assumed by the graphite flakes.

36. This work had to be limited to one composition only, because of the short time and the expenditure involved. However, it is felt that what has been found to be true for the particular iron investigated will hold true for irons of other compositions.

INVESTIGATION OF THE GAS CONTENT OF SUPERHEATED CAST IRON

37. During the past decade, the gas content of metals has attracted the attention of metallurgists because of the important bearing it seems to have on properties and structure of metals.

38. In the case of cast iron, studies of the gas content have not been very numerous. Johnson[15] concludes from his investigation on the effect of oxygen on the strength of cast iron, that irons containing considerable amounts of oxygen are stronger than irons of lower oxygen content. Johnson's claims are supported by the findings if Oberhoffer and Piwowarsky[16].

39. The most recent work on the effect of oxygen in cast iron has been carried out by Eckman and Jordan of the Bureau of Standards, and Jominy of the Engineering Research Department, University of Michigan[17].

40. In the present investigation, it was thought that such a study might assist in understanding the phenomena which are revealed to take place when cast iron is superheated. For this reason, gas analyses were made on superheated irons in the vacuum fusion apparatus of the Department of Engineering Research of the University of Michigan.

41. The results of this investigation are given in Table 4. Unfortunately, the results obtained do not show any possible correlation with the preceding findings. Close examination of Table 4 will show the following facts to be true:

(1) Hydrogen and nitrogen content of the superheated irons do not seem to vary in accordance with any law.

(2) Oxygen content decreases with an increase in superheating temperature.

This latter fact is in agreement with expectations, since it has been proved that, in general, the solubility of gases in metals decreases as the temperature increases.

EFFECT OF POURING TEMPERATURE ON STRUCTURE AND PROPERTIES OF CAST IRON

42. It has long been recognized that the pouring temperature of a metal, which is here defined as the temperature at which the metal is poured into a mold, will materially affect the properties of metals and alloys. A study was therefore made to determine, if possible, the effect of the pouring temperature on the properties of gray cast iron.

43. Procedure followed in making these tests was the same

Table 4

Gas Content of Superheated Gray Cast Iron as Determined by the Vacuum Fusion Method

Heat No.	Superheating Temperature, °F.	Oxygen, per cent	Hydrogen, per cent	Nitrogen per cent
1.	2570	0.0097	0.00008	0.0033
2.	2730	0.0057	0.0001	0.0057
3.	2855	0.0076	0.0001	0.0073
4.	3035	0.0058	0.00003	0.0056
5.	3085	0.0041	0.00015	0.0011
6.	3110	0.0033	0.00008	0.0026

as that used in previous experiments. As soon as the maximum superheating temperature was attained, four standard test bars, 1.2-in. in diameter, were cast, while the rest of the heat was allowed to cool in the furnace. As the temperature dropped, four more test bars were poured. This was repeated four times, giving an iron which had been superheated to a definite temperature and poured from various temperatures.

44. The time elapsed between the pouring of the first and the last set of bars never exceeded 35 minutes. Consequently, as has been shown by Frear[18], no appreciable change in the composition takes place in such a short period of time. In fact, it is believed that similar results would have been obtained if the metal had been allowed to cool in the ladle. The only reason that the metal was allowed to cool in the furnace was that the metal could be kept rocking while cooling. It was also thought that cooling in the furnace would take place at a more uniform rate throughout the molten mass of metal. This condition could hardly be expected to exist when the metal is allowed to cool in a ladle,

Table 5

CHEMICAL COMPOSITION OF GRAY IRONS USED IN STUDY OF THE EFFECT OF POURING TEMPERATURE

Heat No.	Total Carbon, %	Graphitic Carbon, %	Combined Carbon, %	Silicon %
G	3.25	2.71	0.54	2.56
H	3.17	2.56	0.61	2.38
I	3.41	2.61	0.80	2.26
J	3.02	2.25	0.77	2.19

which, from room temperature or slightly higher, attains the temperature of the molten metal within a few minutes.

45. The results of this series of tests are given in Tables 5 and 6 and Figs. 9 and 10. These figures show that for all irons that have been investigated an optimum pouring temperature exists, that above this temperature there is a slight decrease in physical properties and that below this temperature the decrease is of much larger magnitude.

46. Photomicrographic study was made of representative sections of all of these irons. However, it was thought sufficient to report the typical appearance of only one of them in Figs. 11 and 12. In the iron poured at 3030 degrees Fahr., the graphite flakes are smaller and more evenly distributed throughout the matrix than in the iron poured at 2478 degrees Fahr.

47. Apparently, the time during which cooling took place permitted some of the large flakes to partially dissolve and thus decrease in size. As the pouring temperature is further lowered below 2600 degrees Fahr., the size of the graphite flakes becomes larger. This process continues as cooling takes place until 2478 degrees Fahr. is reached, when the finely flaked graphite has almost disappeared. The rather large patches are predominant, and the elongated flakes are much longer and thicker.

48. Parallel with this change in the size of the graphite flakes, Fig. 9—Above, shows the change which has occurred in the physical properties. Photomicrographs of the etched specimens, Fig. 11, will reveal that there is a marked change in the matrix of these irons, which takes place after the pouring temperature is lowered.

49. While the matrix is predominantly pearlite and sorbite, in irons poured from 3030 and 2688 degrees Fahr., in the irons poured from below 2600 degrees Fahr. a coarsening of the pearlite

Table 6

Physical Properties of Irons Superheated and Poured at Indicated Temperatures

Heat No.	Bar No.	Heated to F°.	Pouring Temperature, °F.	Transverse Strength, lb. Max.	Min.	Avg.	Deflection, in. Max.	Min.	Avg.	Tensile Strength lb. per sq. in. Max.	Min.	Avg.	Brinell Hardness, Avg.
G	13–16	3030	3030	2390	2230	2318	0.33	0.28	0.31	38,860	36,955	37,700	212
	1–4		2688	2500	2315	2440	0.35	0.33	0.34	41,520	39,400	40,700	209
	9–12		2599	2360	2130	2247	0.30	0.28	0.29	36,560	33,350	35,340	215
	5–8		2478	2430	1800	2075	0.26	0.21	0.23	35,920	33,770	34,960	206
H	1–4	3034	3034	2625	2450	2522	0.35	0.31	0.33	41,800	40,100	40,850	204
	9–12		2832	2800	2470	2652	0.40	0.32	0.36	43,050	39,750	41,025	206
	5–8		2750	2760	2665	2696	0.35	0.32	0.33	41,600	39,750	40,650	203
	13–16		2458	2450	2340	2396	0.28	0.27	0.27	34,050	32,800	33,720	202
I	9–12	3045	3045	2560	2400	2478	0.27	0.25	0.25	42,812	41,195	42,057	208
	1–4		2729	2610	2470	2542	0.30	0.27	0.29	43,360	41,400	42,600	208
	13–16		2683	2570	2280	2463	0.26	0.23	0.25	41,037	40,413	40,627	212
	5–8		2483	2380	2000	2152	0.28	0.21	0.24	31,256	28,100	30,004	212
J	9–12	2887	2887	2760	2530	2657	0.33	0.30	0.32	38,590	37,530	38,175	202
	1–4		2710	2640	2430	2537	0.34	0.29	0.31	39,720	38,020	38,865	206
	13–16		2667	2650	2350	2503	0.32	0.27	0.29	37,960	36,780	37,357	204
	5–8		2581	2540	2520	2532	0.33	0.31	0.32	37,172	35,626	36,342	202

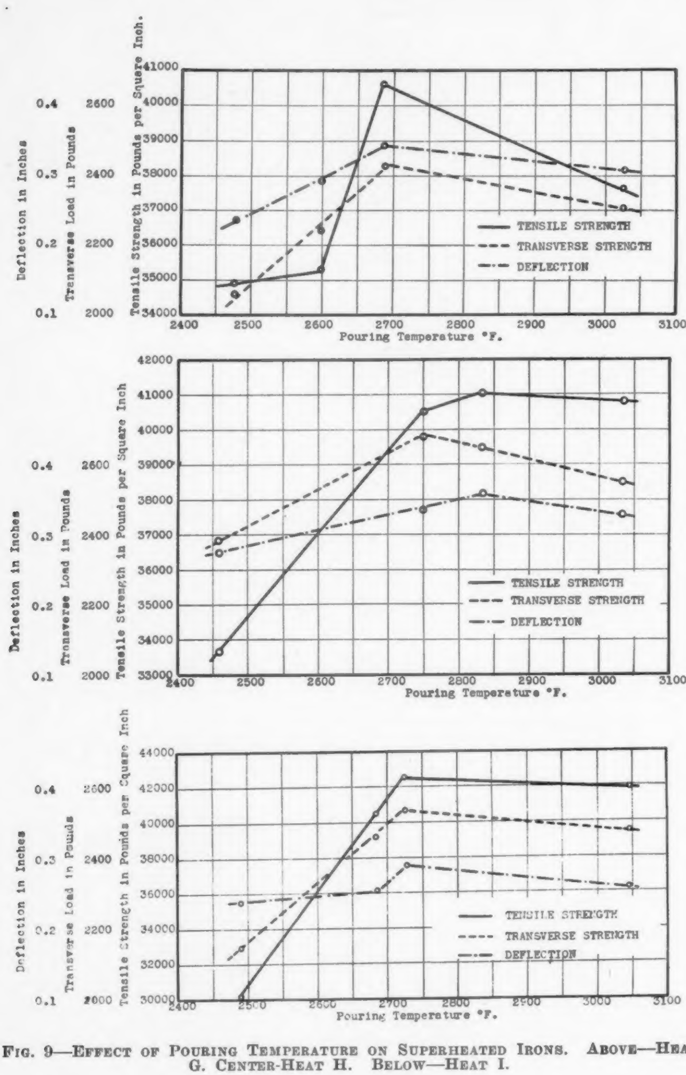


FIG. 9—EFFECT OF POURING TEMPERATURE ON SUPERHEATED IRONS. ABOVE—HEAT G. CENTER-HEAT H. BELOW—HEAT I.

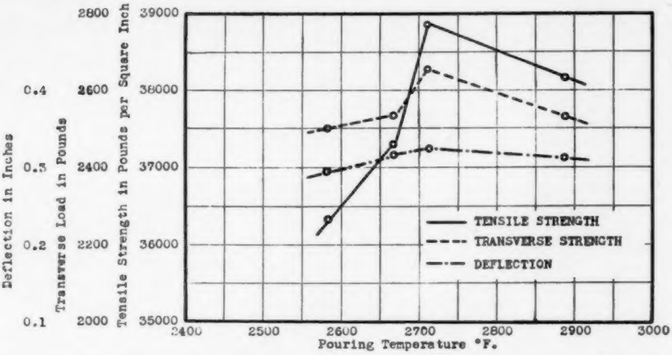


Fig. 10—Effect of Pouring Temperature on Superheated Irons. Heat J.

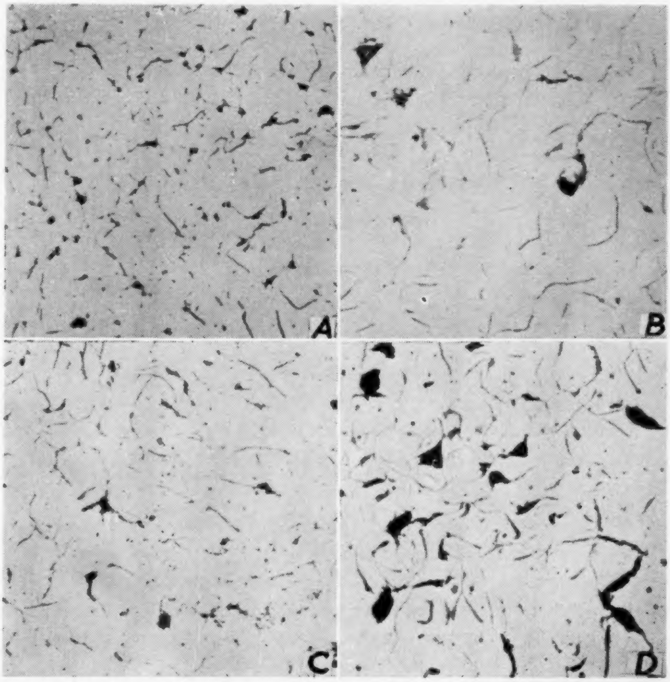


Fig. 11—A—Iron G, Superheated to 3030 Degrees Fahr. and Poured at the Same Temperature, Unetched, x100. B—Same Iron, Superheated to 3030 Degrees Fahr. and Poured at 2688 Degrees Fahr. C—Same Iron, Superheated to Same Temperature, Poured at 2599 Degrees Fahr. D—Iron G, Superheated to 3030 Degrees Fahr. and Poured at 2478 Degrees Fahr.

grains is to be noted together with the appearance of some free ferrite near the graphite flakes. In the iron poured at 2475 degrees Fahr., the amount of free ferrite is increased, showing that the carbon has migrated from the pearlitic grains and deposited itself on the existing grains of graphite.

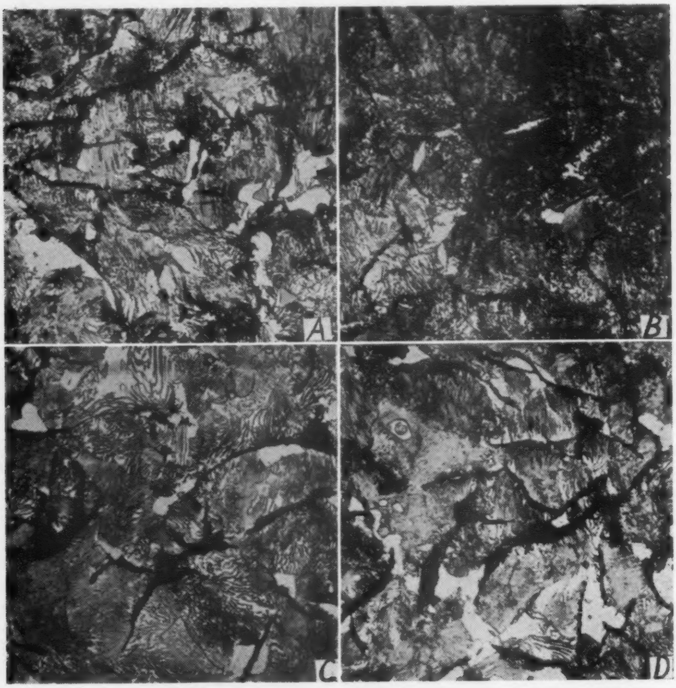


FIG. 12—A—SAME AS FIG. 11-A, ETCHED, x500. B—SAME AS FIG. 11-B, ETCHED, x500. C—SAME AS FIG. 11-C, ETCHED, x500. D—SAME AS FIG. 11-D, ETCHED, x500. (REDUCED 1/3 IN PRINTING.)

50. Some of the phenomena here reported have been noticed by other investigators. Frear has stated that holding molten cast iron at temperature will result in better physical properties, because it produces a refinement of the graphite flakes.

SUMMARY OF FINDINGS

51. The investigation of factors affecting the structure and properties of gray iron may be summarized as follows:

Effect of Superheating

52. Superheating of cast iron refers to the process in which molten iron is heated to temperatures much higher than the melting point and the pouring temperature. Such a process has been known to improve the physical properties of cast irons. Present knowledge is, however, only qualitative.

53. The results of the present investigation, so far as the effect of superheating is concerned, are briefly summarized as follows:

(1) Superheating within limits improves the physical properties of cast iron.

(2) Its beneficial effect, for the iron investigated, becomes noticeable at about 2700 degrees Fahr., and reaches a maximum at about 3035 degrees Fahr.

(3) Too high a superheating temperature is detrimental to cast iron. The lowest superheating temperature which produces detrimental or non-beneficial effects is referred to as the "critical superheating temperature".

(4) The beneficial effects of superheating are primarily the results of a refinement of the graphite flakes. It is believed that such refinement is influenced by the mode of formation of graphitization nuclei primarily in the liquidus-solidus range.

(5) Cast irons heated at or above the critical superheating temperature possess low physical properties. This is believed to result from agglomeration of the graphite flakes in a dendritic pattern, since the axes of the dendrites constitute planes of weakness.

(6) The critical superheating temperature has been established for irons of different composition.

(7) It has been proved that the critical superheating temperature is lower, the lower the total carbon content of the iron.

Effect of Pouring Temperature

54. Some confusion exists as to the meaning of the term "pouring temperature". In this investigation, the pouring temperature is the temperature taken in the ladle just before the metal is poured into the molds.

55. The results of this research may be summarized as follows:

(1) The pouring temperature has a definite effect upon the physical properties of cast iron.

(2) An optimum pouring temperature exists which varies for different irons investigated within the range of 2680 and 2850 degrees Fahr.

(3) Cast irons poured from temperatures either above or below this range have lower physical properties than irons poured within the range.

(4) Cast irons poured from temperatures higher than the optimum range show both coarse and fine graphite flakes. This condition results in a material of non-uniform properties.

(5) Cast irons poured from too low a temperature show excessively large graphite flakes. The reason for this is to be found in the fact that pouring from such a low temperature will result in a slower rate of cooling in the molds which permits graphitization to occur to a great extent. The formation of large graphite flakes effectively breaks up the continuity of the matrix, thus producing a weak iron.

THE FORMATION OF THE DENDRITIC PATTERN OF GRAPHITE IN CAST IRON

56. In this study of the effects of superheating on the properties of cast iron, it has been shown that a temperature exists in the neighborhood of 3080 degrees Fahr., which is referred to as the "critical temperature," above which the physical properties of the irons investigated are greatly reduced. Above this temperature, the graphite exists, not in the common flaky form, but as very fine curved flakes which outline a dendritic pattern. It was believed that the critical temperature was related to the carbon and silicon content of the iron. It was thought that this critical temperature would be lower, the lower the carbon content. Hence, it became necessary to investigate the formation of the dendritic pattern in superheated irons.

57. This investigation consisted in taking irons of the same silicon content, but with varying amounts of total carbon, superheating them to various temperatures, and noting the appearance of the graphite flakes.

58. Table 7 gives the chemical composition and history of

Table 7

Relationship of Chemical Composition and Superheating Temperature to Appearance of Graphite

Heat No.	Super-Heating Temper-ature °F.	Pouring Temper-ture °F.	T.C., %	G.C., %	Si., %	Appearance of Graphite
6	3110	2740	3.23	2.48	2.27	Dendritic Pattern
5	3085	2730	3.26	2.53	2.31	"
CB	2995	2710	2.87	1.94	2.24	"
CA	2940	2705	2.41	1.61	2.25	"
FA	2935	2695	2.64	1.54	2.31	"
CC	2925	2695	2.24	1.47	2.27	"
1	3045	2729	3.41	2.61	2.26	Curved Flakes
4	3035	2730	3.26	2.48	2.22	"
CE	2940	2700	2.78	1.83	2.24	"
CD	2895	2710	2.32	1.54	2.29	"

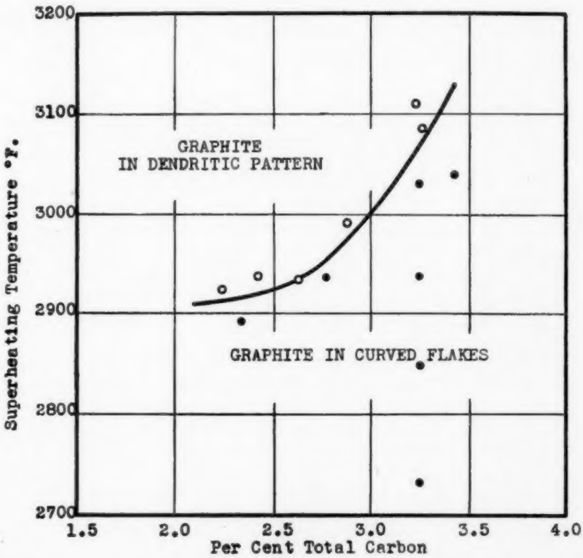
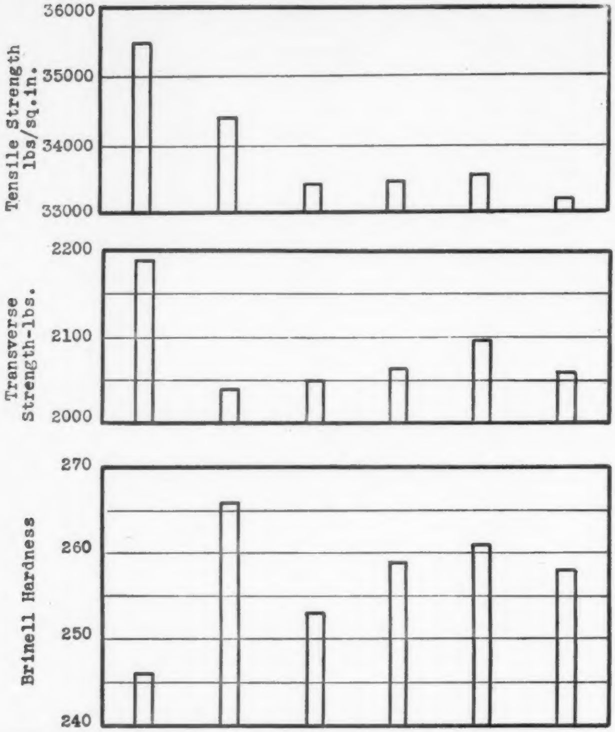


Fig. 13—Formation of Dendritic Graphite as Affected by the Superheating Temperature for Cast Irons Containing 2.25 Per Cent Silicon.

these irons. Table 8 shows the average physical properties. These two tables are represented graphically in Figs. 13 and 14.



Heat NO.	VI	V	CB	CA	FA	CC
Composition T.C.	3.23	3.26	2.87	2.41	2.64	2.24
Si.	2.27	2.31	2.25	2.25	2.31	2.27
Superheating Temperature °F.	3110	3085	2995	2940	2935	2925
Pouring Temperature °F.	Same for all, about 2700°F.					

FIG. 14—PHYSICAL PROPERTIES OF IRONS SHOWING DENDRITIC PATTERN OF GRAPHITE.

Fig. 13 shows the per cent total carbon plotted against the superheating temperature.

59. Fig. 13 shows that above the line, graphite is present in the dendritic form, and below the line, it is present in a flaky form. Such a line merely marks a transition zone, and, while the temperatures given will apply for this particular iron and the particular conditions of melting and rate of cooling, they cannot be taken as absolute values for irons of other compositions, and melted under different conditions.

Table 8

Physical Properties of Irons Showing Dendritic Pattern of Graphite

Heat No.	Transverse Strength, lbs.	Deflection, in.	Tensile Strength, lbs. per sq. in.	Brinell Hardness
6	2192	0.282	35,500	241*
5	2040	0.212	34,400	261*
CB	2048	0.210	33,400	248**
CA	2065	0.210	33,475	254**
FA	2092	0.207	33,540	256**
CC	2060	0.210	33,200	253**

* Average values of eight specimens.
** Average values of four specimens.

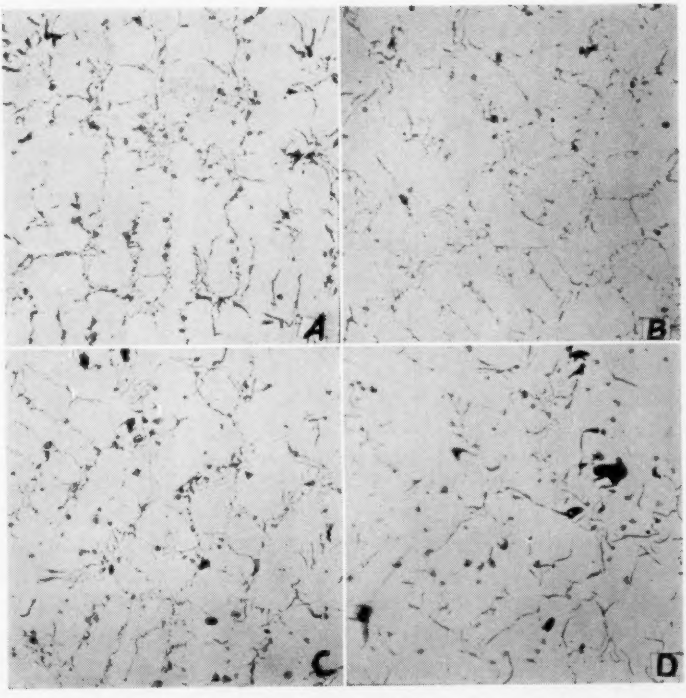


Fig. 15—Structure of Cast Irons Superheated to Too High a Temperature Showing Dendritic Pattern of Graphite. All Specimens Unetched. A—Iron 5, Superheated to 3085 Degrees Fahr. and Poured at 2730 Degrees Fahr. B—Iron CB. Superheated to 2995 Degrees Fahr. and Poured at 2710 Degrees Fahr. C—Iron FA, Superheated to 2735 Degrees Fahr. and Poured at 2695 Degrees Fahr. D—Iron CC, Superheated to 2925 Degrees Fahr. and Poured at 2695 Degrees Fahr. All Micrographs, x100.

60. This line also shows that, as the carbon content is decreased, the lowering of the critical temperature seems to approach the equilibrium value which would indicate that for carbon content below 2.24, the critical temperature may still be around 2900 degrees Fahr. Physical properties of these irons are plotted in Fig. 9. The diagram shows that the physical properties of these irons, which show dendritic patterns of the graphite, are nearly the same, with the possible exception of the first two, the total carbon of which is much higher than the others.

61. This fact is well worth attention because it substantiates the opinion that the physical properties of cast iron are

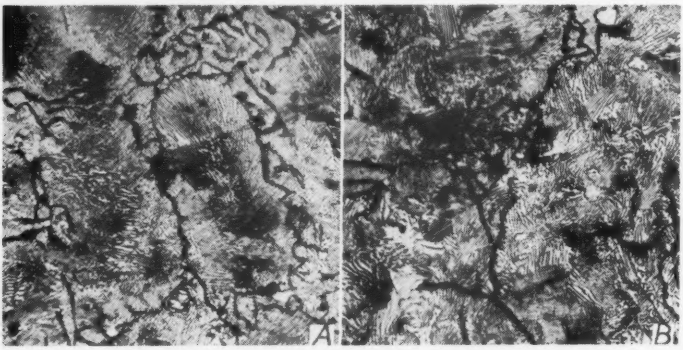


FIG. 16—LEFT—SAME AS FIG. 15-A, ETCHED, x500. RIGHT—SAME AS FIG. 15-D, ETCHED, x500. (REDUCED 1/3 IN PRINTING.)

primarily dependent upon the distribution and size of the graphite flakes. Figs. 15 and 16, showing micrographs of these irons, are presented here to illustrate this particular grouping of the graphite which is the same for all the irons regardless of the carbon content. From this study, it may be safely deduced that the critical superheating temperature, which brings about the formation of the dendritic graphite pattern, is lower, the lower the carbon content of the irons. Consequently, care should be exercised in the production of high strength irons so as not to reach this temperature.

62. The existence of this agglomeration of graphite in commercial cast irons has been reported only in a few instances. It has been found in some of the irons quenched in mercury from the liquidus line by Tanimura. No attention, however, has been paid to it by previous investigators.

63. In many commercial products, on the other hand, especially in the so-called high-test irons, one can see very often the beginning of such dendritic pattern, and cases have been reported by foundry metallurgists of this peculiar pattern of graphite, for which no explanation could be offered. Evidently the temperature to which the molten metal was heated had been such that the critical temperature was reached, or even surpassed.

INVESTIGATION OF THE PRESENCE OF GRAPHITE IN MOLTEN GRAY CAST IRON

64. To explain the effects of superheating and pouring temperatures, the hypothesis was advanced that, under commercial conditions of manufacturing cast iron, graphite will not pass entirely into solution at the eutectic and liquidus temperatures.

65. The existence of graphite in molten cast iron has been denied by many prominent metallurgists, especially by Honda and Murakami,[19] who, in their study of the graphitization of pure iron-carbon alloys, came to the following conclusion:

> "The graphite in pure cast iron is produced by the decomposition of solidified cementite and not by the direct separation from the melt. Flaky graphite is also obtained by annealing the solidified alloy at a temperature a little below the eutectic point."

66. In commercial melting practice, conditions are somewhat different, since a large amount of silicon is present in these alloys. Graphite flakes are present in pig and cast irons used in making up the charge in the furnace, and the time allowed for heating and melting is not sufficiently long to permit all the graphite to go into solution in the melt.

67. To prove the validity of the hypothesis, it was thought necessary to quench various cast irons heated to about the following temperatures: 2300, 2500, 2700, and 2950 degrees Fahr. If graphite were present in the melt at these temperatures, drastic quenching, *i.e.,* in water at room temperature, will retain such graphite, and the chemical and microscopical analysis will show the amount and size of the graphite flakes, respectively.

Experimental Procedure

68. This series of experiments was carried out in a high-frequency induction furnace. Fig. 17 represents the assembled apparatus. It will be noted that the quenching tank was situated

4 in. below the crucible, so that it was only a matter of a fraction of a second before the molten cast iron was plunged into the water, and thus the possibility of an appreciable drop in temperature before quenching was avoided.

69. The procedure was as follows: About 150 grams of iron were placed in a crucible 3 in. long, 5/8 in. inside diameter, and

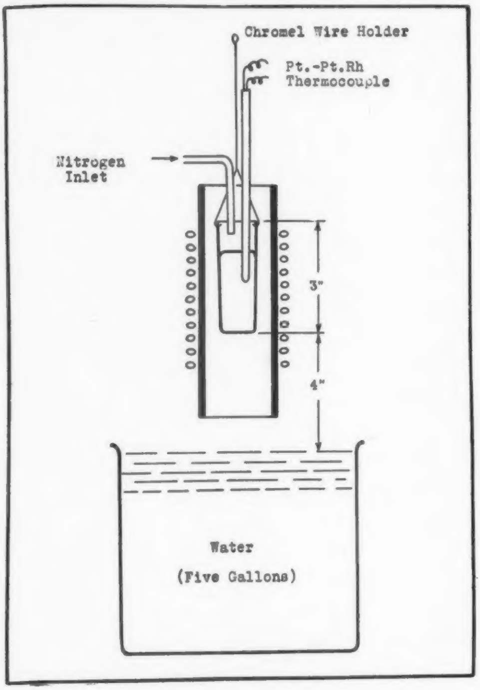


FIG. 17—APPARATUS USED FOR MELTING AND QUENCHING SAMPLES OF CAST IRON.

about 1/16 in. in thickness. This crucible was held by a chromel wire at such a height in the furnace that the wires would not melt. The protection tube carrying the platinum-platinum-rhodium thermocouple was made to rest on top of the metal and arranged in such a way that, as the iron melted, the thermocouple could freely sink into the metal for about one inch. Nitrogen

gas was made to flow into the furnace so as to keep the atmosphere around the metal as non-oxidizing as possible. As the power was turned on, the heating of the metal was followed by means of the thermocouple.

70. As soon as the metal had reached the desired temperature, the wire holding the crucible was cut and the metal dropped

Table 9

Amount of Graphite Retained in Cast Irons Quenched from Indicated Temperatures

Quenched from °F.	Graphite per cent		T.C., %	Si., %
		Iron A		
2215	2.10		3.16	2.09
2455	0.53			
2715	0.14			
2930	0.09			
		Iron E		
2300	2.03		3.15	2.22
2505	0.54			
2730	0.27			
2940	0.06			
		Iron D		
2290	2.85		2.98	2.50
2505	1.32			
2725	0.18			
2930	0.07			
		Iron X		
2275	2.95		3.50	3.62
2490	2.81			
2595	2.75			
2950	2.13			

into the quenching tank. A precaution had to be taken at this point to avoid a spattering of the metal and the possibility of the crucible breaking on hitting the bottom of the quenching tank. This was accomplished by having on top of the water muslin cloth which acted as a parachute and retarded the downward speed of the metal. The quenching of the sample was very rapid, indeed; as soon as the metal had reached the bottom of the tank, it could be handled.

Results

71. The quenched specimens were cut and samples were

taken for chemical and microscopical analysis. Table 9 gives the chemical composition, the per cent graphite retained after quenching, and the quenching temperature. These data are plotted graphically in Fig. 18. The curves as given in Fig. 18 are not to be taken as solubility curves, since it is expected that they may be influenced by a time factor; nevertheless, it is felt that they closely represent the solution process of graphite when cast iron is produced under commercial conditions.

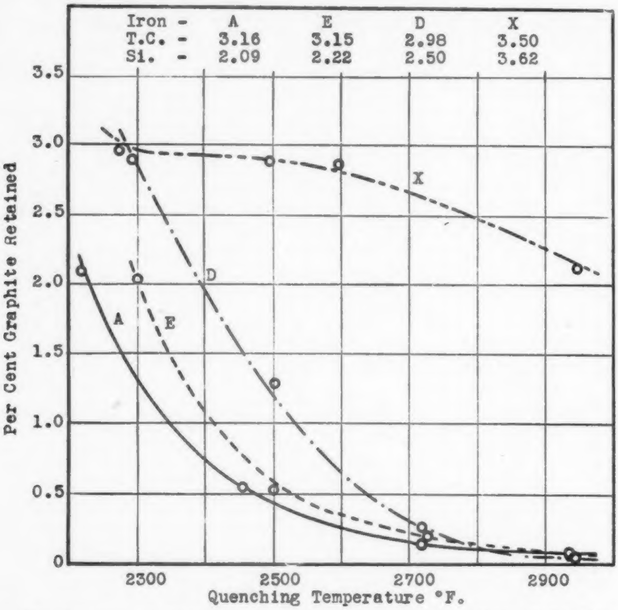


FIG. 18—AMOUNT OF GRAPHITE RETAINED IN QUENCHED LIQUID CAST IRON.

72. A photomicrographical study was made of representative sections of the quenched cast irons. Fig. 19 shows the appearance of graphite flakes in the unetched condition. They are included as further evidence of the presence of graphite flakes in cast iron quenched from the molten state. It is to be noted that a relatively high magnification was necessary to bring out the graphite particles, since, due to their smallness at low magnification, they can easily be taken for polishing pits. Honda and Murakami, in the work referred to, emphatically denied the existence of any graphite in molten Fe-C alloys of the cast iron

type. It is worthy of mention, however, that they offered no chemical analyses, and their photomicrographic work was carried out at magnifications ranging from 10 to 180 diameters; consequently, the detection of such small particles of graphite was very difficult.

73. In examining the curves of Fig. 18, it is evident that,

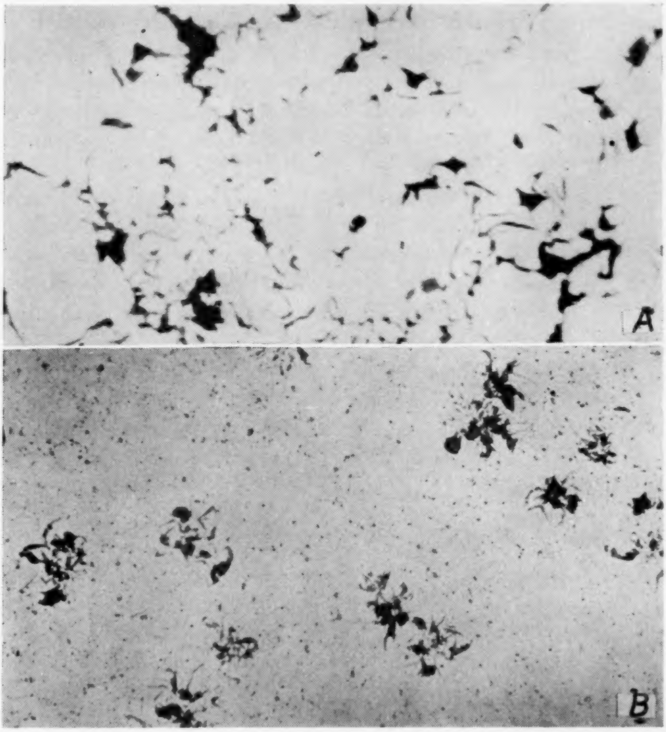


Fig. 19—Graphite Flakes in Cast Iron Quenched from the Molten State.
A—Iron E, Quenched in Water from 2730 Degrees Fahr., Unetched, x1000
B—Iron X, Quenched in Water from 2595 Degrees Fahr., Unetched, x100.

for all the irons investigated, the amount of graphite present in the melt decreases as the temperature of superheating increases. It can be seen that at temperatures in the neighborhood of 2300 degrees Fahr. the amount of graphitic carbon still present is only slightly less than the amount which would be expected at room temperature in the same irons produced under normal conditions.

As would be expected, graphite goes into solution rapidly as the temperature is increased, and, at least for the three commercial irons, *A, E,* and *D,* the amount undissolved reaches an equilibrium value when 2950 degrees Fahr. is attained.

74. Comparing the curves for irons *A* and *E,* that is, irons of the same carbon content, but with 2.09 and 2.22 per cent silicon respectively, it is noticed that the graphite retained at any temperature is greater for iron *E,* the difference being more evident at the lower temperatures. This observation is in agreement with the well-known fact that silicon promotes graphitization. Also, on the basis of these findings, together with the results of the investigation of the effect of the superheating temperature, the following deduction is justified: the superheating temperature necessary to bring about the refinement of the graphite flakes, is lower, the lower the silicon content of the cast iron.

75. Iron *X* was investigated because its composition is within the limits of a commercial foundry pig iron. It will be seen that the amount of graphite retained in the melt by this iron is very appreciable, and that even at 2700 degrees Fahr., 2.75 per cent of the total carbon is still present as graphite. Recalling the fact that pig irons of composition similar to iron *X* are, in general, used in making up the charge for producing cast iron, the result of this investigation warrants the following conclusion: In the commercial production of cast irons, if high physical properties are desired, either the amount of pig in the charge has to be reduced, or a high superheating temperature has to be attained to avoid the presence of excessively large graphite flakes.

76. It has been pointed out that the curves of Fig. 18 are not to be taken as solubility curves, since it was expected that the length of time at temperature might affect the amount of graphite retained in the melt. To ascertain the possible effect of holding at temperature on the amount of graphite in the melt, the following experiments were conducted.

77. Samples of iron *E* were melted, heated to 2730 degrees Fahr., held at this temperature for various lengths of time, and then quenched in water, as in the previous experiments. Another sample of this iron was heated to 3000 degrees Fahr., cooled to 2730 degrees Fahr. and then quenched The object was to find out whether the graphite, once put in solution, could reprecipitate when the melt was cooled from 3000 to 2730 degrees Fahr. The results of these tests are given in Table 10. This table is

Table 10

THE EFFECT OF TIME AT TEMPERATURE ON THE AMOUNT OF GRAPHITE RETAINED IN CAST IRON AT 2730 DEGREES FAHRENHEIT

Time in Minutes	Quenching Temperature, °F.	Graphite, per cent
	Iron E*	
0	2730	0.26
12	2730	0.21
20	2730	0.024
40	2730	0.023
60	2730	0.011

Iron E, heated to 3000 degrees Fahrenheit, cooled to 2730 degrees Fahrenheit, and quenched has 0.023 per cent graphite.
* T.C. = 3.15 ; Si. = 2.22.

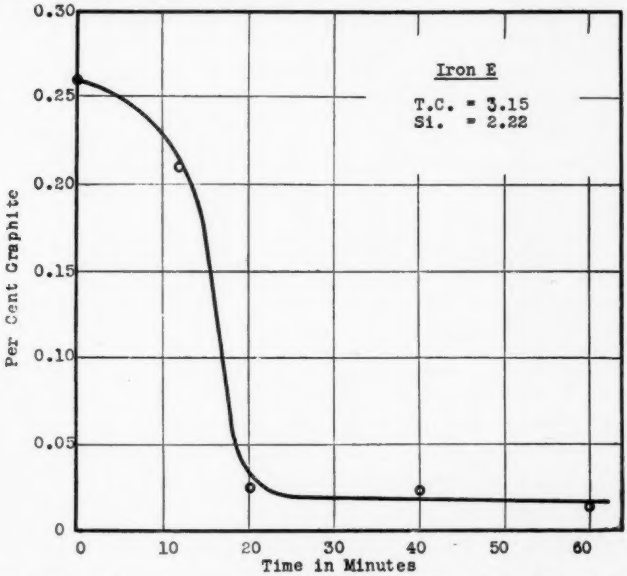


FIG. 20—GRAPH SHOWING THE RATE OF SOLUTION OF GRAPHITE IN IRON E *at* 2730 DEGREES FAHR.

presented graphically in Fig. 20, which shows that a relatively long time is required, at a temperature of 2730 degrees Fahr., to dissolve all the carbon which is still present as graphite.

78. Although the experiments were carried out at only one temperature, it is logical to assume that at temperatures below

2730 degrees Fahr., a longer time is necessary to dissolve all of the graphite, an conversely, a shorter time is required for temperatures above 2730 degrees Fahr.

Conclusion

79. The results of these experiments substantiate the view which was advanced in explaining the effect of the pouring temperature on the properties and size of the graphite flakes in cast iron. It will be recalled that better physical properties; namely, smaller and more uniform graphite flakes, were obtained in irons poured at temperatures lower than the superheating temperature, specifically at temperatures between 2680 and 2850 degrees Fahr. In the light of these experiments, it can be seen that cooling from maximum superheating temperature to pouring temperature has offered the opportunity for graphite flakes to completely pass in solution in the melt.

80. These experiments are also in agreement with the conclusion reached by Frear,[18] who, in studying the effect of holding molten cast iron at temperatures in the neighborhood of 2600 degrees Fahr., ascribes the better physical properties of irons held at temperature to a refinement which has taken place in the graphite flakes.

81. The experiment on the sample of iron *E*, heated to 3000 degrees Fahr., cooled to 2730 degrees Fahr., and quenched, indicates that the graphite, once put in solution, cannot be reprecipitated in the melt.

RECOMMENDATIONS

82. From the results obtained in this study, it would seem that, to produce unalloyed cast irons of higher physical properties than are obtained at the present, the following facts should be considered:

(1) For the great majority of commercial cast irons, the superheating temperature should not exceed 3000 degrees Fahr.

(2) If such a high temperature is difficult to attain, as in the case of cupola melting, holding the metal at a lower temperature for a relatively longer period of time will produce a comparable degree of refinement of the graphite flakes.

(3) Whenever possible, cast iron should be poured into the molds at a temperature of around 2700 degrees Fahr.

(4) In compounding the charge to be melted for making

cast iron, care should be taken to avoid pig or cast iron scrap which shows excessively coarse graphite flakes. Such flakes will have a greater tendency to remain undissolved and result in coarsely flaked cast iron.

(5) Care should be exercised in superheating cast iron so as not to reach the critical superheating temperature, which produces irons of relatively high hardness and low tensile strength.

ACKNOWLEDGMENTS

83. The authors wish to thank the faculty of the Department of Metal Processing, University of Michigan, for the use of the foundry in which most of the work was carried out; also to thank L. A. Delp and R. H. Rodrian for their aid in carrying out the chemical analyses of the irons.

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DISCUSSION

R. A. CLARK[1] (*Submitted in Written Form*): The authors are to be congratulated on the quality and amount of data presented in this paper. It gives evidence of an enormous amount of thoughtful work, executed and presented in a thoroughly capable manner.

I was exceptionally interested in their work as it deals with a subject that is one of my particular hobbies. I have had considerable experience (much of it sad) in the melting of gray irons for special applications and have gradually formed a theory on the subject of super-heat and its effect on graphite structure, strength and heredity of gray irons and it was particularly gratifying to have this theory verified on almost every point by this paper.

I should like to ask the authors the following questions as to the preparation of the base cupola melted iron and their melting practice: (1) What were the proportions of pig, steel and scrap used? (2) Was the entire heat tapped into the ladle for use as base metal or were the first and last iron pigged as in normal foundry practice? (3) What was the estimated temperature at the cupola spout? (4) The cupola base iron carries 3.36 per cent carbon and 2.00 per cent silicon. The remelted iron averages 3.27 per cent carbon and 2.26 per cent silicon. Does this difference represent carbon loss and silicon pick-up on remelting or is it the result of additions to the base metal? (5) How much time elapsed during melting and superheating an electric furnace heat to 2750 degrees Fahr.

I am rather at a loss to understand the low strength of 26,800 lb. per sq. in. on the cupola melted iron as it is a rather simple thing to produce unalloyed cylinder irons in the cupola showing 35,000 to 38,000 lb. per sq. in. tensile strength with a Brinell hardness of 200 in arbitration bar sections.

The authors show very conclusively that the optimum superheating temperature of this particular iron melted under the given conditions is in the neighborhood of 3035 degrees Fahr. I believe that this optimum temperature will be found to vary considerably with analysis, method of melting, composition of slags, speed of melting and graphite concentration in the original charge. In other words, it is a matter of temperature, time, mass and heredity. I believe that irons of relatively high carbon, silicon and phosphorus contents will stand a relatively high superheating temperature and that reduction of any of these elements which automatically raises the liquidus temperature, will also lower the optimum superheating temperature of the metal. This is not a matter of concern in cupola operation but in electric melting with comparatively slow melting and the ease of reaching high temperatures, it is rather easy to overheat irons of low carbon and phosphorus contents.

As to the experiments on pouring temperatures, they indicate to me that the best pouring temperature for this iron is that which will give the quickest cooling from 2700 degrees Fahr. to below the solidus. Extremely hot pouring will heat the mold and slow cooling through this range. Cold pouring evidently allows the superheat reaction to reverse itself in the ladle and although there may be sudden solidification upon introduction into the mold, the coarse nuclei prevent the proper degree of supercooling

[1] Lakey Foundry & Machine Co., Muskegon, Mich.

necessary for fine graphite formation. The optimum pouring temperature may be altogether different for a mold having heavier or lighter sections. The results do indicate that most small gray iron castings are poured too cold to develop maximum physical properties, and that strength is often sacrificed to produce a smooth, neat appearing casting.

The authors' proof of the existence of free graphite in molten irons was certainly ingenious and should add considerably to our knowledge of this frequently debated subject.

R. S. MACPHERRAN[2] (*Submitted in Written Form*): This paper is very interesting especially as showing the detrimental effect of a too high superheating temperature on low carbon iron. References to the proper pouring temperature also open up a new field for thought.

I noted particularly the section on dendrites. The authors refer to the lower strength of this structure. This is probably true although we have had some very high tensile tests with structures showing a dendritic pattern. I would be glad to hear as to whether this dendritic effect or pattern is permanent in a melted iron.

For example, if this is once introduced by superheating and the metal is held for a considerable time below the temperature of this dentritic formation, is there a tendency to form flake graphite and have this dendritic pattern disappear, or if test bars are poured from a very hot ladle and the same show a dendritic pattern, will the casting which is poured somewhat later have the same dendritic effect, or does this type of structure tend to change back to the flake graphite on standing at a lower temperature? Also, would there be any tendency for this condition to persist through a re-melting operation?

We have frequently noticed that a change in the etch will either bring out this formation or obscure it. After a very light etch for example, it is often visible while a slightly heavier etch will often hide it.

We have heard of several methods of preventing the production of an iron showing this formation, but would be interested in hearing of some method of destroying this property in the ladle.

A. I. KRYNITSKY[3] (*Submitted in Written Form*): The authors should be congratulated on the research work they carried on and reported in their paper.

A number of investigators have studied the effect of superheating on cast iron and as yet the mechanism of graphite formation is not completely solved. The work carried on by the authors is of particular interest to the writer as the phase of the work reported in their paper is somewhat similar to the experiments now being carried on in the Metallurgical Division of the National Bureau of Standards.

According to the authors some graphite remains undissolved in the molten gray iron even at the temperature as high as 3000 degrees Fahr. (1650 degrees Cent.) and graphite, once put in solution, cannot be reprecipitated in the melt. Assuming that the graphite observed by the authors in their quenched specimens of gray cast iron is not the product of decomposition of cementite, one may offer the explanation of the phenomenon observed quite different to that which was advanced by the authors.

[2] Chief Chemist, Allis-Chalmers Mfg. Co., Milwaukee, Wis.
[3] Associate Metallurgist, National Bureau of Standards, Washington, D. C.

According to Tammann[4], the crystallization of a melt is determined by the factors: "Nuclei number" and the "Velocity of crystallization". The mode of undercooling depends upon the values of those factors and their proportion to each other. Nipper[5] states that the first effect of high superheating is to decrease viscosity. Impurities in the melts, consisting of coarse or of more or less dispersed oxides, silicates, etc., coalesce and are separated out. According to him, even in the case of hypereutectic melts, all particles of graphite are entirely dissolved. The high degree of purity thus attained allows for an extensive undercooling of the melt. With this point of view the authors' results may be explained by assuming that during the cooling of the molten gray iron nuclei of primary graphite are formed and the freer the melt is from impurities the less graphite will be precipitated. A very small amount of graphite found by the authors in iron *E* heated to 3000 degrees Fahr. (1650 degrees Cent.) cooled to 2730 degrees Fahr. (1500 degrees Cent.) and quenched compared with the same iron heated to 2730 degrees Fahr. (1500 degrees Cent.) and quenched is probably due to the greater number of nuclei, upon which graphite is precipitated, being destroyed by the higher temperature.

One may also assume that the iron heated to 2730 degrees Fahr. and held there for 60 minutes may contain less nuclei than the same metal held at the same temperature for a shorter period of time.

This seems to the writer to be a more logical explanation of the effect of superheating upon the graphite formation in the molten iron. Some experiments have been carried on at the National Bureau of Standards by quenching samples of the molten cast iron in ice water and also by permitting samples to air-cool. Graphite containers coated with a refractory material were used for sampling liquid metal at different superheating temperatures and as the metal cooled in the furnace.

The data obtained do not warrant definite conclusions. However, there are some indications that the primary graphite possibly is formed in the molten iron.

A. E. CARTWRIGHT* (*Submitted in Written Form*): Messrs. Di Guilio and White's contribution represents a remarkably useful and painstaking research in which guess work has apparently been eliminated as far as is humanly possible, and they are accordingly to be congratulated.

The first feature which commands attention is the method of determining temperatures and the writer would be interested to learn whether this apparatus is, or is likely to become, a commercially practical instrument in the foundry. It is quite evident that many of the observations and deductions made, could not have been so authoritatively produced if arrived at by the aid of an optical instrument. Details regarding the manufacturers of this thermocouple and millivoltmeter, its cost, and the life of the thermocouple in terms of number of immersions would be welcome.

The writer is also particularly interested in the data given regarding the effect of superheating to a point where a dendritic structure of graphite

[4] Tammann, G., *"Kristallisieren und Shmelsen,"* 1903

[5] Nipper, H., *"Constribution to the Study of Graphite Formation and Structure in Cast Iron and its Influence upon the Properties of the Cast Metal,"* FOUNDRY TRADE JOURNAL, vol. 51, 1934, pp. 7-14.

* Chemist and Metallurgist, Robert Mitchell Co., Ltd., Montreal, P. Q., Canada.

flakes is produced. The elimination or control of this condition has puzzled him for some time.

In the refining of graphite by superheating, this condition frequently occurs, chiefly in irons of the lower carbon ranges, producing disappointingly low transverse and deflection figures. This effect is not produced alone by superheating, but by any factor influencing the refining of the graphite flakes beyond a certain stage, such as alloy additions, particularly calcium silicide and titanium. Perhaps it would be more correct to say that, in the presence of such alloys, a lower maximum superheating temperature is desirable to avoid dendritic graphite.

Seemingly, when efforts are made to refine graphite size beyond a certain degree, no matter by what means, we run into difficulties in the matter of poor distribution of the graphite, and a distinct retrogression in physical properties. The matter of distribution of the graphite has been slurred over in a great deal of the literature devoted to high test irons with "super refined" graphite and the writer appreciates the arrangement of the text of paragraph 61 in which "size and distribution" are reversed.

In paragraph 59, the authors rightly limit their findings to the melting and cooling conditions of the particular iron discussed. In this connection, the writer would like to remark that in a recent experiment in producing a high test iron with very refined structure, that while microstructure of a ½-in. step bar section and that of the 1.2-in. transverse bar showed definitely dendritic graphite, the microstructure of a section taken from the center of a 6-in. diameter by 6-in. block was not in the least dendritic though of considerably coarser graphite. Furthermore, the fine sorbitic pearlite produced in the small sections was not noticeably coarsened in the section from the block. The Brinnell hardness was uniform from outside to center of the block.

Therefore, while the refining of graphite to a dendritic stage would be detrimental for the smaller sections, for castings of heavy section, or otherwise slow cooling, the advantages of the initial refinement of both graphite and matrix becomes evident.

C. H. Lorig[6]: The superheating of cast iron, within limits, may or may not improve its properties. While in this paper the conclusion is reached that it does, under some conditions and with some cast irons, superheating has no effect whatever. Examples of irons which do not respond to superheating have been frequently mentioned in the literature and no further comments on this point are necessary.

The temperature at which the dendritic pattern is formed was shown to be affected by both carbon and silicon. Beside these elements, other alloying elements influence the presence of the dendritic pattern. We have noticed that a dendritic structure is sometimes obtained upon superheating to 2600 degrees Fahr. and that this structure can be destroyed by adding alloys. In one instance, a heat of metal melted in a Detroit electric furnace, and superheated to about 2650 degrees Fahr. produced castings with a dendritic pattern when no alloying additions were used. Castings from a second ladle of metal taken about half a minute later, to which a little copper was added, had normal structures, indicating that this dendritic pattern can be destroyed by changing conditions in the metal.

[6] Battelle Memorial Institute, Columbus, O.

The approximate transverse strength of the metal before and after alloying, when measured over a span of 18 in., was about 2000 lb. for the unalloyed and about 3200 lb. for the alloyed iron. The properties of the metal were distinctly improved by distributing the graphite in the normal plate-like form.

In regard to the effect of the gas content on superheated cast iron, the statement is made that the oxygen content decreases with an increase in superheating temperatures and that this was in agreement with expectations because it has been proved that, in general, the solubility of gases in metals decreases as the temperature increases. Sieverts, and later Iwase, found that just the reverse was true, that the solubility of gases usually increases as the temperature increases. I wondered whether there were not other factors that might explain the decrease in oxygen which the authors report.

Since the oxygen content decreases, it would indicate to me that silicates or other oxides are being reduced by the carbon or by the silicon in the melt, so that the resulting effect is a decrease in oxygen content along with a decrease in the number of slag inclusions. According to the hypothesis of von Keil, the change in the number of inclusions will account for the difference in graphite distribution in the iron.

The result of the oxygen determination seems to indicate that reduction of the inclusions in the metal actually took place.

The statement is made that the hydrogen and nitrogen contents of the superheated irons do not vary in accordance with any law. It probably depends on whether the metal is saturated or unsaturated with the gases.

G. P. PHILLIPS[7]: About three years ago we did some work at Frank Foundries Corp., Moline, Ill., on the superheating of cupola melted alloy iron and plain cast iron, that is, iron non-alloyed, and iron that had steel in the mixture and iron that had no steel in the mixture. I do not recall the exact figures, but the alloy iron was tapped from the cupola at around 2800 degrees Fahr. After superheating, it showed no improvement in physical properties and in most cases, I think we found a decided drop in toughness as measured by transverse resilience. There was an increased tendency to chill and an increase in stiffness, as measured by the modulus of elasticity at about one-fourth of the transverse load.

In the case of the iron that was made with a pig-scrap mixture and with no steel, there was a decided improvement in the iron. The tensile strength and the transverse resilience were increased.

As a result of the tests, our conclusions were that, in general, the steel mix alloyed irons were not materially improved in fact, in some cases the physicals were decreased; whereas the plain pig-scrap metals were improved by superheating.

DR. H. A. SCHWARTZ[8]: In the diagram (Fig. 18), in which a variety of irons were given and figures plotted as to the amount of graphite that they contained after melting and heating to the various temperatures, the upper curve is a high silicon, fairly high carbon iron, possibly a hypereutectic iron. I wondered whether in that case the persistence of graphite flakes, or the persistence of what results in graphite flakes, at any rate,

[7] Metallurgist, International Harvester Co., Chicago, Ill.
[8] Manager of Research, National Malleable and Steel Casting Co., Cleveland, O.

is to be construed as a decreased solubility of graphite in the presence of the 3 per cent silicon, or whether that is merely a sloping up of the solubility. If such an experiment had been made as is plotted in the graph of Fig. 20, and if that same iron had been held for a long time at one of those temperatures, I wonder whether a decrease in graphite to the few hundredths of a per cent that was otherwise observed in the other irons would, also have been encountered.

DR. DIGIULIO: Answering Dr. Schwartz' question. We did not run that series of tests with that particular iron, keeping it at a certain temperature for a certain length of time, but I think that if the experiment is carried out, we will find that probably over a longer period of time, most of that graphite will disappear.

CHAIRMAN J. T. MACKENZIE[9]: I would like to call attention to the omission of George K. Elliott's name from this short bibliography. It seems to me that Elliott's work along about 1919 or 1920 was the most important boost for superheating that has been done. I am sure the authors did not omit his name intentionally.

I would like to call attention to the recent papers by Piwowarsky, in which he takes a specimen of cast iron and holds it for eight to ten or twelve seconds in hot copper and then quenches, and he finds that this extremely rapid heating results in the solution of all the graphite that can be observed up to 500 diameters. In the case of very high silicon irons, you can actually see it recrystallize in an entirely different pattern, so it must have gone into solution.

DR. DIGUILIO: In answering the Chairman's question as to Piwowarsky's latest experiment, I had a talk with Professor Piwowarsky last year and the way he explained the experiment to me, he actually pulled the metal out and then dropped it in the water and the time elapsed was rather considerable. He was not so sure himself at that time but I do not know whether he is sure now.

MR. LORIG talked about the oxygen content of these irons and I think I will call on Dr. Murphy, who ran these experiments, to answer that.

DR. D. W. MURPHY[10]: The thing that strikes me about oxygen determinations in cast iron is that, in general, it seems that it is not the amount of oxygen which appears to have an effect but rather the way in which it is combined and, for that reason, I rather hesitate to say that a small decrease in the total oxygen content may be the governing factor. Rather, I think we should know more about how the oxygen exists than what its total amount is.

In regard to the statement that solubility of gases decreases with increasing temperature, I do not think that that can be upheld.

DR. DIGIULIO (*Written Reply to Discussion*): The authors wish to thank all those who by their discussions have materially increased our knowledge of the fundamental facts underlying the properties of gray cast iron.

To the questions asked by Mr. Clark, the following answer may be

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[9] Chief Chemist and Metallurgist, American Cast Iron Pipe Co., Birmingham, Ala.

[10] Dept. of Engineering Research, University of Michigan, Ann Arbor, Mich.

given. The entire heat was pigged in the ladle. The temperature at the spout was not taken; however, not much cooling took place during the pouring operation. The change in chemical composition, in the case of carbon, may be considered a very small loss on remelting, while in the case of silicon the increase was brought about by the addition of ferrosilicon; the time elapsed during the melting and superheating of a 250 lb. heat to about 2700 degrees Fahr. was on the average 70 minutes.

Mr. McPherran asks whether the dendritic pattern is permanent with a given iron. The experience of the writer is that the dendritic pattern of the graphite will disappear, if, upon remelting, the iron is heated to the proper temperature. The writer does not have any evidence which will permit him to state that the dendritic pattern may disappear if the melt is held at a lower temperature.

Mr. Cartright asks the question as to the practicability of the immersion pyrometer used to measure the temperature. The writer knows of one large foundry which has used this type of pyrometer. A serious objection to its use is due to the fact that the time required to take a temperature reading is longer than the time required by an optical pyrometer; it has, however, two inherent advantages: (a) it eliminates the human element, (b) it is not affected by smoke screen, dust, or changing emissivity of the metal. The life of the noble-metal thermocouple depends entirely upon the thickness of the end of the graphite protection tube which, in the case of the type used by the writer, was 1⅛ in. diameter and lasted for about 15 immersions.

Col. Krynitsky offers another valuable viewpoint in explaining the effect of superheating. It is true that superheating will decrease viscosity, since the viscosity of most liquids is a direct function of the temperature. However, we do not have enough experimental evidence to prove that oxides and silicates will coalesce and separate out. For this reason, we cannot believe that these facts alone will cause a high degree of purity, which would permit an abnormal under-cooling of the melt.

If we accept Nipper's opinion that all particles of graphite are entirely dissolved, it becomes hard to explain the well known fact that a pig or a gray cast iron, which exhibits coarse graphite flakes, will on remelting give a metal with coarse graphite flakes, and, furthermore, it is only through several remeltings that the coarseness of the graphite flakes can be reduced. Apparently we are dealing here with a case of inoculation and, as Bossu[11] has pointed out, the precipitation is due primarily to the formation and growth of independent crystal nuclei rather than to an increase in size of the seed crystals. Also the work of Marcelin[12] proves that finely divided particles of a substance are more effective in producing spontaneous crystallization than the same substance in the form of larger particles.

Dr. Lorig, in his discussion, points out that a small addition of copper will destroy the dendritic pattern. The writer believes that the addition of alloying elements will affect the formation of the dendritic graphite, but he wishes to point out that his experience is that gray iron, even with high copper content, may show dendritic graphite.

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[11] Bossu, R. G., *"Compt. Rend."* 177,119-21 (1923).
[12] Marcelin, R., *"Compt. Rend."* 148,631-8 (1909).

A Study of an Industrial Application of the Martensitic Transformation of Austenitic Iron

By George R. Delbart,* Denain, France

Abstract

This paper discusses data on an austenitic iron which can be hardened by low temperature annealing which gives it a martensitic structure. The iron contained approximately 3.75 per cent manganese and 6.5 per cent nickel. The mechanical properties varied with the temperature of the anneal. With an annealing temperature of 1112 degrees Fahr., the Brinell hardness was 418. This hardness figure was lowered as the temperature of the anneal was raised beyond 1112 degrees. Tensile strengths were approximately 29,000 lbs. per sq. in. in the "as-cast" condition, but on annealing at 1112 degrees Fahr. this was increased to approximately 46,000 lb. per sq. in. Light castings, such as steam engine valves, have been produced of this iron, but from data obtained it is quite evident the shock resistance of this martensitic iron is inferior to pearlitic cast iron and consequently is better fitted for use in heavy castings.

1. There is one problem which frequently presents itself in industrial practice. It consists of producing castings which are hard but machinable and consequently may be fitted to precise dimensions.

2. It has not been possible to solve this problem with plain gray or white irons. Plain gray irons easily machinable in the as-cast state, are not suitable for quenching in water or oil. Their response to heat treatment usually is not sufficient to harden them by air quenching. The white irons, which are very hard as-cast are machinable with difficulty, as in the case of simple shapes such as rolls for rolling mills. It is necessary then to have recourse to special cast irons.

3. Two methods are possible:

(a) To prepare gray iron, and consequently a machinable iron, containing special elements capable of conferring

* Chief Engineer of Technical Metallurgical Service, Establishments Cail.

Note: This paper was presented at a session on Cast Iron at the 1935 Convention of A.F.A. in Toronto, Canada.

upon it a susceptibility to hardening, by simply cooling it in air, or if necessary in oil, to produce a martensitic structure. We know that water quenching of carbon steels is a very delicate operation, and it will likewise produce cracks or microscopical fissures in cast irons.[1] This is the reason why plain gray iron ought not be considered in the problem studied here.

(b) To prepare an iron austenitic as cast and consequently machinable, containing special elements in such a quantity that it is possible, by means of heat treatment, to transform the austenite into martensite of hardness suitable for practical purposes.

PREVIOUS INVESTIGATIONS

4. The first progress made in France toward the solution of this problem was through the researches of Leon Guillet, Jean Galibourg and Marcel Ballay,[2] who studied in particular the influence of nickel as an alloying element. Later, additional researches on the same subject were presented[3] and included studies on the influence of manganese in such amounts, that the effects of this element could be observed. The completion of this work outlined the possibilities and the effects of a combined action of nickel and manganese[4] with a view toward obtaining an austenitic iron at a reasonable cost and also possible to manufacture easily. This concluded with a study of the combined action of nickel and manganese, which lead to a practical solution of the second case mentioned in the theories outlined above.

INFLUENCE OF NICKEL AND MANGANESE

5. Without reviewing in detail the influence of various alloying elements, it is necessary to say a few words about the action of nickel and of manganese. Nickel favors the graphitization and tends to refine the texture of the cast iron. It stimulates the response to quenching. The manganese if present in excessive amounts favors the initial quenching (as in quenching white

[1] Portevin, A.—*On the Thermal Treatment of Castings and Especially Projectiles of So-called Steel Bearing Cast Irons.* COMPTE-RENDU 1922-2, 175, p. 27.

[2] Guillet, L., Galibourg, J., Ballay, M., *Researches on Martensitic Quenching and the Thermal Treatment in Hardening of Castings*, REVUE DE METALLURGIE, Nov. 1931.

[3] Delbart, G., and Lecoeuvre, E., *Contribution to the Study of Cast Irons with a Low and a Very Low Content of Carbon*, BULLETIN ASSOCIATION TECHNIQUE DE FONDERIE DE FRANCE, September 1932.

[4] Delbart, G. R., *Martensitic Quenching of Cast Iron*, TRANS. AMERICAN FOUNDRYMEN'S ASSN., vol. 41, 1933, pp. 20-50, and BULLETIN ASSOCIATION TECHNIQUE DE FONDERIE DE FRANCE, June 1934.

iron) and stabilizes the cementite. It stimulates at the same time the second or martensitic quenching property.

6. On the one hand the nickel and the manganese act in the same way from the point of view of martensitic quenching, and both lower the transformation points on cooling, while on the other hand the action of manganese tending to promote the formation of hard spots during primary cooling—a bad thing from the view of machinability—is counter-acted by the presence of nickel.

The Iron Developed

7. Among casting compositions containing nickel-manganese made in the cupola in the course of this study, one of them showed itself particularly able to transform the austenitic structure, which it possessed in the as-cast condition, into the martensitic structure and vice-versa. It could be used successfully for industrial purposes. Its chemical composition was: total carbon 2.65 per cent, graphitic carbon 1.65 per cent, combined carbon 1.00 per cent, silicon 1.81 per cent, phosphorus 0.074 per cent, sulphur 0.025 per cent, manganese 3.75 per cent, and nickel 6.50 per cent.

Dilatometric Tests.

8. Dilatometric tests with a Chevenard dilatometer, which registers automatically, revealed after a heating in excess of 1832

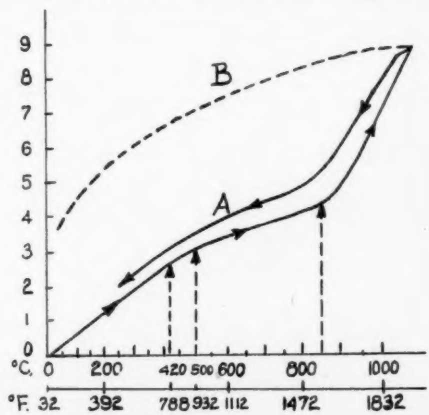

Fig. 1—Reproduction of Curves Obtained with the Chevenard Differential Dilatometer. The Solid Line Curves Are for a Cooling Rate 17 Degrees Cent. (30.6 Degrees Fahr.) Per Minute Between 1000 Degrees Cent. (1800 Degrees Fahr.) and 400 Degrees Cent (752 Degrees Fahr.). The Dotted Line Curve Is for a Cooling-by-Air Blast at a Rate Exceeding 200 Degrees Cent. (360 Degrees Fahr.) Per Minute.

degrees Fahr. (1000 degrees Cent.) a strong stability to the action of heat, and the cooling curve for a rate of 30.6 degrees Fahr. (17 degrees Cent.) per minute was almost superimposed on the heating curve. In the course of the test two transformation points were obtained: one between 752 and 932 degrees Fahr. (400 and 500 degrees Cent.) and the other one between 1472 and 1562 degrees Fahr. (800 and 850 degrees Cent.).

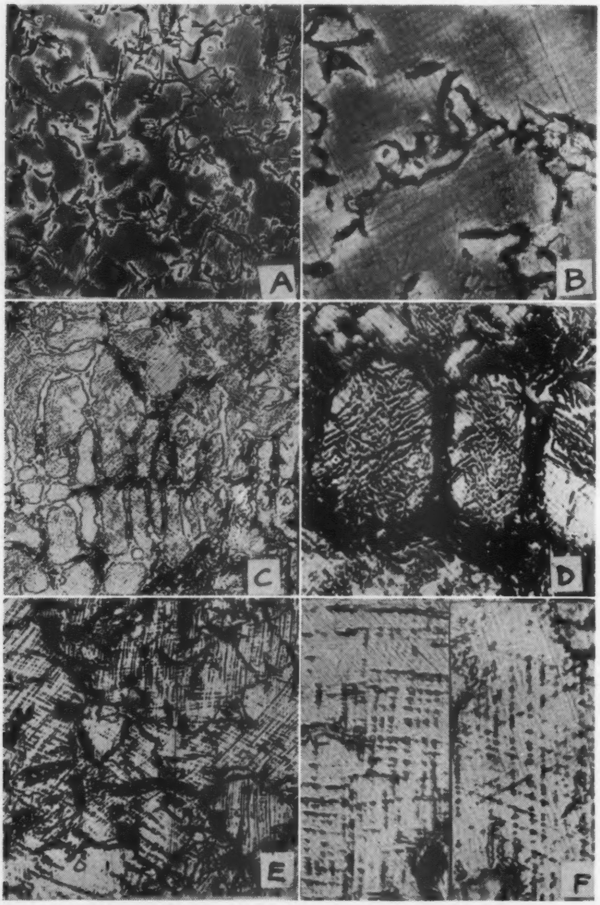

FIG. 2—MICROGRAPHS OF THE IRON IN "AS-CAST" AND ANNEALED CONDITION. (A) "AS-CAST" CONDITION x 50; (B) "AS-CAST" CONDITION x 400; (C) ANNEALED 2 HOURS AT 500 DEGREES CENT. (932 DEGREES FAHR.) x 50; (D) IRON OF (C) x 400; (E) ANNEALED 6 HOURS AT 500 DEGREES CENT. (932 DEGREES FAHR.) x 100; (F) IRON OF (E) x 400.

9. Finally cooling by air blast after reheating to 1940 degrees Fahr. (1060 degrees Cent.) indicated the absence of all transformation upon cooling and consequently a hyper quenching (Fig. 1). The micrograph revealed in the as-cast condition a graphite austenite structure. The latter formed a solution, the heterogeneity of which was revealed by the appearance after picric acid etching of the shadowy outline of primary dendrites (Fig. 2 A and B).

10. Annealing at 932 degrees Fahr. (500 degrees Cent.) the critical temperature indicated in the dilatometrical test, produced after 2 hours an initial decomposition of the austenitic background, which was indicated by the appearance of martensitic needles in the carbon poor regions of the solid solution and through a precipitation of carbide in the carbon rich regions occupied by the austenite (Figs. 2C and D). A reheating at 932 degrees Fahr. (500 degrees Cent.) was extended for 6 hours showing a new stage in the formation of the martensite which affected the pure geometric forms of the kind observed by Belaiew in the Widmanstaetten structure (Figs. 2E and F). Finally after a reheating of 20 hours at 932 degrees Fahr. (500 degrees Cent.) all the austenite was transformed into martensite and even ferrite halos had formed around the graphite in the zones which corresponded with that portion of the solid solution that had been heavily drained of carbon due to the precipitation of graphite.

Mechanical Properties

11. These structural modifications were evidently accompanied by variations in the mechanical properties and the study of the influence of time in the anneal at 932 degrees Fahr. (500 degrees Cent.) shows that the maximum hardness was practically attained after 10 hours of heating. To be sure to be in the proper time limits for the treatment, a period of 15 hours was adopted to study the influence of the anneal as a function of the temperature. The results of this study with regard to the hardness, transverse, shearing, tensile, elastic limit E, and elastic modulus tests are shown in Table 1 and in the diagrams of Figs. 3 to 6 inclusive.

12. The curves (Figs. 3 to 6) show a sharp variation of all the mechanical properties starting from heat treatments about 752 degrees Fahr. (400 degrees Cent.) Brinell hardness, shear strength, transverse strength, and tensile strength, and elastic limit increase sharply and reach a maximum at 1112 degrees

Fahr. (600 degrees Cent.) then diminish to descend again around 1652 degrees Fahr. (900 degrees Cent.) to values lower or equal to the original values, while the elongation and the deflection are practically constant till 752 degrees Fahr. (400 degrees Cent.)

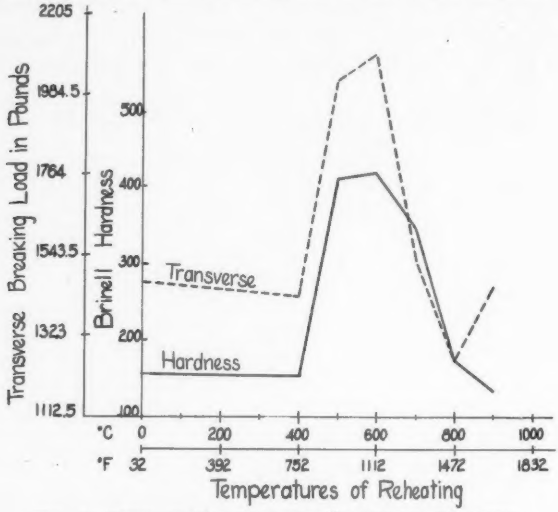

FIG. 3—TESTS OF HARDNESS AND TRANSVERSE STRENGTH

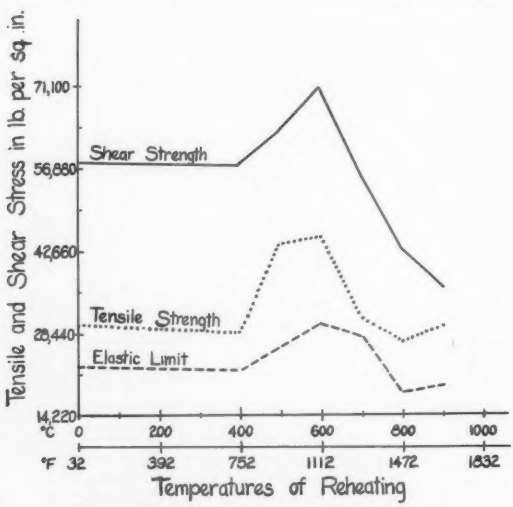

FIG. 4—TENSILE AND SHEAR TEST RESULT.

Table 1

VARIATIONS OF THE MECHANICAL PROPERTIES AS A FUNCTION OF THE TEMPERATURES OF THE ANNEAL*

Temp. of Anneal Degrees Fahr.	Degrees Cent.	Brinell Hard-ness Number	Tensile Strength lbs per sq. in.	Elastic Limit lbs per sq. in.	Elon-gation Per Cent	Shear Strength lbs. per sq. in.	Trans-verse Break in load	Deflec-tion mm.	Modulus of Elasticity lbs. per sq. in.
59	15	160	28,720	22,752	1.40	58,530	1488	0.42	16,779,000
752	400	150	28,010	21,330	1.60	58,586	1323	0.41	18,770,000
932	500	415	42,800	....	0.75	65,420	1939	0.20	....
1112	600	418	46,310	30,570	0.65	73,940	2116	0.25	15,357,600
1292	700	340	31,990	27,020	0.60	55,880	1550	0.27	15,642,000
1472	800	170	27,730	17,775	0.50	44,940	1259	0.21	15,642,000
1652	900	134	30,573	18,480	......	37,498	1455	0.22	12,940,000

*Anneal period, 15 hours.

diminishing suddenly between 752 and 932 degrees Fahr. (400 to 500 degrees Cent.) thereafter remaining constant up to 1472 degrees Fahr. (800 degrees Cent.).

13. The following figures are a summary of the results reported: Brinell hardness, 418; tensile strength, 46,300 lb. per sq.

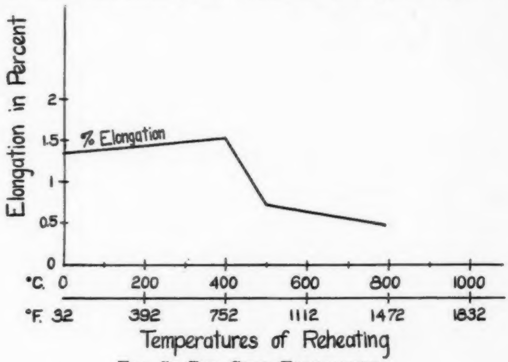

FIG. 5—PER CENT ELONGATION.

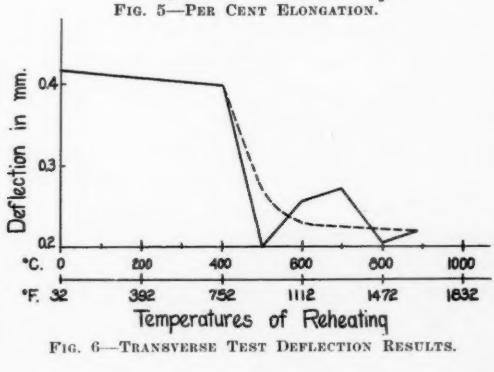

FIG. 6—TRANSVERSE TEST DEFLECTION RESULTS.

in.; elastic limit, 30,570 lbs. per sq. in.; shear strength, 73,940 lbs. per sq. in.; transverse breaking load, 2,116 lbs.; deflection, 0.25 mm., and modulus of elasticity, 15,357,600 lbs. per sq. in.

14. This summary shows that the material studied is capable of becoming alternately austenitic and martensitic, which is to say that it can be made to vary from a hardness of 130 to 460 Brinell by means of simple heat treatments, which render it especially valuable in certain cases. In addition, it possesses excellent mechanical properties, if it is annealed at 1112 degrees Fahr. (600 degrees Cent.) for 15 hours.

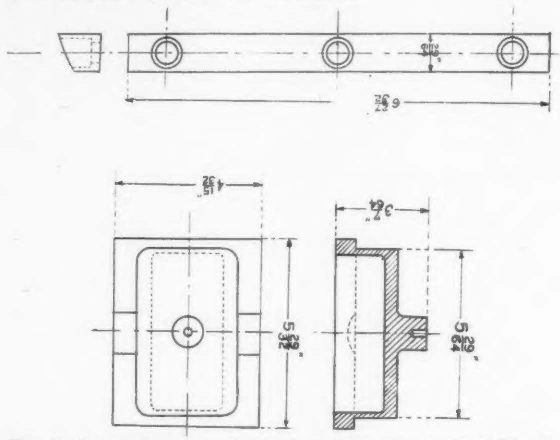

FIG. 7—STEAM CYLINDER VALVE ABOVE AND SLIDE VALVE BELOW.

APPLICATIONS

15. It can be added that the resulting cost of this material is not excessive since to attain the austenitic condition requires only a content of 3 to 4 per cent manganese and 6.5 per cent nickel. Obviously the availability of a commercial product of this type is worthy of attention, and it will be interesting to advance its study and use in castings.

16. As a result of these tests and by testing this cast iron from all angles, light castings have been produced such as steam engine valves and valve guides (Fig. 7) which castings are actually in service. It is quite evident that the shock resistance of martensitic cast iron is inferior to pearlitic cast iron and it is consequently better fitted for use in heavy castings where there is no risk of shock.

Recommendations of the A. F. A. Committee on Chemical Classification of Foundry Steels

Increasing use of alloys in the steel castings industry and the consequent increase in the number of types of steel used in the commercial production of steel castings, has resulted in considerable confusion regarding designations applied to the various classes of cast steel. To aid in the standardization of designations which might be used for the various steels used for castings, a committee of the Steel Division was appointed about two years ago to formulate recommendations for the classification of foundry steels. This committee has made a very detailed study of the problem and has submitted the report given below, which will be discussed at one of the steel sessions at the Toronto Convention in August.

1. Chemical composition of cast steel shall be identified and described from the standpoint of what is intended, without regard for the presence of any element not purposely introduced into the steel. The descriptions herein therefore relate only to what is desired and have been prepared for use prior to manufacture.

2. Cast steel shall be known as "medium carbon" cast steel when all of the following chemical restrictions are intended to be observed: A carbon content no lower than 0.12 per cent and no higher than 0.49 per cent; a manganese content no lower than 0.50 per cent and no higher than 1.00 per cent; a silicon content no lower than 0.20 per cent and no higher than 0.75 per cent; a phosphorus content no higher than 0.05 per cent; a sulphur content no higher than 0.06 per cent; and the absence or negligible content of any other element.

3. Cast steel shall be known as "low carbon" cast steel when the carbon content is to be lower than 0.12 per cent and when the composition otherwise is to be as described herein for "medium carbon" cast steel.

4. Cast steel shall be known as "high carbon" cast steel when the carbon content is to be higher than 0.49 per cent and

NOTE: This report was presented at a session on Steel Founding at the 1935 Convention of A.F.A. in Toronto, Canada.

when the composition otherwise is to be as described herein for "medium carbon" cast steel.

5. Carbon cast steels, whenever possible, should be specified according to the grade designations found in A.S.T.M. specifications.

6. Cast steel shall be known as "alloy" cast steel when the composition is to include more manganese, silicon, or special elements than those described herein for the "medium carbon," "low carbon," and "high carbon" varieties. Therefore, cast steel shall be known as "alloy" cast steel when it contains more than 1.00 per cent manganese, or more than 0.75 per cent silicon, or a devised addition (such as chromium, copper, molybdenum, nickel, tungsten, vanadium, etc.) or a combination of any of these items.

7. Cast steel shall be known as "medium-manganese" cast steel when the manganese content is to be no lower than 1.00 per cent and no higher than 3.00 per cent. When a supplementary special element is to be introduced in the manufacture of medium manganese cast steel, the product shall be known by distinctive terms indicating the presence of medium manganese and the supplementary special element. For example, when molybdenum is to be introduced in making medium manganese cast steel, the product shall be known as "medium manganese-molybdenum" cast steel; if vanadium is to be employed with medium manganese cast steel, the product shall be known as "medium manganese-vanadium" cast steel; etc.

8. Alloy cast steels, whenever possible, should be specified according to A.S.T.M. Specifications A-148, which differentiate the grades and classes of steel covered therein, only in respect to permissible heat treatments and to minimum physical properties. When it is desired to meet the requirements of any grade in these specifications with a steel of a particular composition, the steel may be further classified according to *type* by designating it by the standard chemical symbols indicative of the special alloying elements contained (without giving numerical percentages) and by indicating the class and grade. A chromium-vanadium steel treated to meet the requirements of Class B, Grade 2 steel can be designated, for example, as "B-2—Cr-V" steel.

NOTE: The Steel Founders' Society of America (the trade association of the steel casting industry) has originated the differentiating bases of 0.12 per cent and 0.49 per cent, shown above, for classifying low carbon, medium carbon, and high carbon cast steel. These limits have been ac-

cepted by the A.F.A. Committee submitting the above recommendations in order that the latter may be in conformity with the limits established for commercial application through action taken by the Steel Founders' Society of America.

Respectfully submitted,

COMMITTEE ON CLASSIFICATION OF FOUNDRY STEELS

C. H. LORIG, *Chairman*
R. A. BULL
A. W. GREGG
JOHN HOWE HALL
W. C. HAMILTON
BRADLEY STOUGHTON

Report of A.F.A. Cost Committee

The subject of foundry cost methods was one of the first given consideration at an A.F.A. convention after its organization in 1896 and this discussion resulted in the formation of an A.F.A. Cost Committee which, at the Philadelphia Convention in 1907, presented its first report recommending the preparation of a chart outlining the main divisions of costs. At this same meeting Ellsworth M. Taylor presented a paper on "Uniform Foundry Costs." From that time on practically every convention has had papers or committee reports on this subject, mainly devoted to fostering uniform cost systems.

In 1914 a Cost Committee was appointed, with A. O. Backert as chairman. The committee's objective was to compile a report that would present a cost system "which would be simple, yet sufficiently comprehensive for satisfactory application to cost accounting in almost every casting plant." This committee reported at the 1915 Convention[1].

The 1915 report of the Cost Committee resulted in the employing of a Cost Expert, C. E. Knoeppel & Co., and the preparation of a cost system, which at first was available to those foundries contributing to a special fund. Knoeppel & Co. prepared an elaborate cost system and serviced the foundries which had contributed to the special fund. However, in 1919 this cost system was given to the general membership of the A.F.A. and was printed in the TRANSACTIONS[2].

It was soon realized that this system was not perfect, especially for the smaller foundries, and the Cost Committee continued its efforts to throw more light on systems which were better adapted for the smaller foundries. At the June, 1922, convention, the committee presented an outline form for a simple system[3].

In the succeeding years the Cost Committee realized that no one system would be suitable for all classes of foundries and it

[1] *"Report of A.F.A. Committee on Uniform Costs,"* TRANS. A.F.A., vol. 24, pp. 61-73 (1915).

[2] *"Cost Accounting System,"* TRANS. A.F.A., vol. 28, pp. 65-140 (1919).

[3] *"Report of Cost Committee,"* TRANS. A.F.A., vol. 30, pp. 282-304 (1922).

enunciated certain basic principles[4]. Later meetings other papers were presented and discussed[5, 6, 7, 8, 9, 10, 11, 12, 13].

Later it was decided that the A.F.A. Cost Committee should do all in its power to foster the use of the cost systems which had been developed by the Steel Founders' Society, The Malleable Iron Research Institute, and the recently formed Gray Iron Institute.

With the forming of the Gray Iron Institute the three ferrous branches of the casting industry were provided for and the A.F.A. Committee was put under the chairmanship of J. L. Wick, Jr., and meetings held to interest the nonferrous foundrymen in adopting a uniform cost system. At the cost session held at the 1930 convention, C. S. Humphreys presented a talk on "Organizing a Nonferrous Foundry Cost Group." At this same meeting the Standard Cost System for the recently formed Gray Iron Founders' Society was presented and discussed[14].

A joint cost conference was held at the 1932 convention with the Gray Iron Institute, at which A. E. Grover presented an extensive paper[15] comparing cost methods.

At the 1933 convention the Cost Committee, under the chairmanship of J. L. Wick, presented a play, the purpose of which was to stress the importance of true cost data.

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[4] *"Report of Cost Committee,"* TRANS. A.F.A., vol. 32, part 1, pp. 29-31 (1925).

[5] *"Departmental Costs in the Foundry,"* May, H. B., TRANS. A.F.A., vol. 32, p. 1, pp. 32-43.

[6] *"Cost Finding in a Foundry,"* Corbette, W. J., TRANS. A.F.A., vol. 32, part 1, pp. 44-78 (1924).

[7] *"An Explanation of a Foundry Cost Method,"* Runge, E. T., TRANS. A.F.A., vol. 33, pp. 148-154 (1925).

[8] *"Progress in Cost Accounting in Industry,"* McCullough, E. W., TRANS. A.F.A., vol. 34, pp. 9-24 (1926).

[9] *"Cost Systems for a Small Foundry,"* Belt, R. E., TRANS. A.F.A., vol. 34, pp. 25-44 (1926).

[10] *"A Uniform Cost System for a Local Group,"* Carter, J. L., TRANS. A.F.A., vol. 35, pp. 20-31 (1927).

[11] *"Seven Years of Foundry Cost Accounting,"* Wessling, A., TRANS. A.F.A., vol. 35, pp. 32-37 (1927).

[12] *"Group Foundry Costs,"* McDaniels, Don, TRANS. A.F.A., vol. 35, pp. 38-44 (1927).

[13] *"Cost Finding Practice for Steel Foundries"* (System prepared for Steel Founders Society), TRANS. A.F.A., vol. 36, pp. 25-62 (1928).

[14] TRANS. A.F.A., vol. 38, pp. 577-623 (1930).

[15] *"Joint Conference on Costs,"* TRANS. A.F.A., vol. 40, pp. 461-482 (1932).

Open Meeting of the Cost Committee at the 1935 Convention.

At the convention of the Association held in Toronto in August 1935, and under the chairmanship of Sam Tour, the Cost Committee held an open meeting. The meeting was attended by approximately sixty members of the Association and the discussions were joined in by many of those present. The primary purpose of the meeting was to get suggestions from members of the A.F.A. as to what the Committee could do to assist in the work of promoting proper cost accounting in the foundry industry.

Since the 1933 convention, a nonferrous foundry cost system had been developed by the Association formed in that field, so that now each of the principal branches of the foundry industry has a cost system.

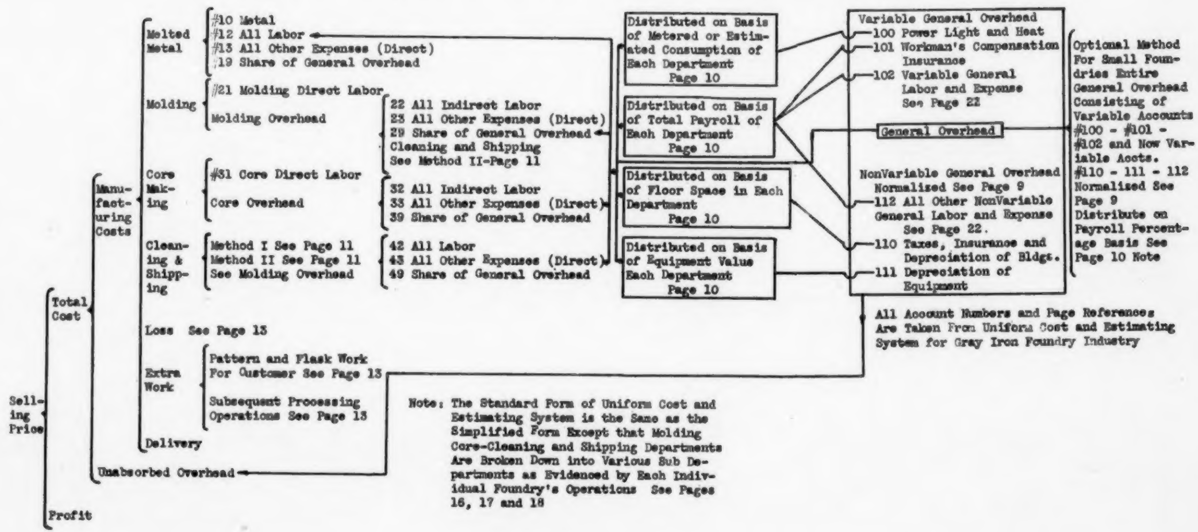
In order to assist in discussions at this open meeting, charts had been prepared of three of the four cost systems in the industry. No chart had been prepared for the Steel Foundries' cost system. These three charts of the Gray Iron Foundry System, the Malleable Iron System, and the Nonferrous Foundry System, showed not only the similarities but the dissimilarities between these standard systems.

Discussion brought out that possibly the charts as drawn up stressed the dissimilarity in the systems more than the similarity. All of the four branches of the foundry industry have about the same operations; namely—melting, molding, coremaking, and cleaning, with the Malleable Iron branch having two cleaning departments and an annealing department in addition. With these same fundamental operations in the four branches of the industry, the various systems do have inherently the same type of departmental cost breakdown.

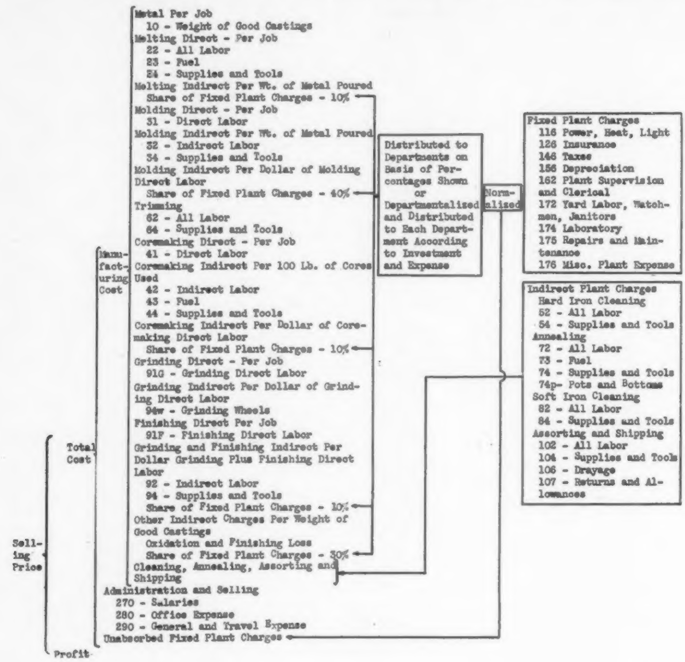
It was the sense of the meeting, therefore, that, instead of submitting the charts as prepared for that meeting with the report of the Committee for publication, the charts should be revised in order to show the similarity more clearly between the cost systems. This work was to be undertaken by the Cost Committee as soon as possible. Unfortunately, one of these cost charts disappeared at the convention.

THE GRAY IRON FOUNDRY INDUSTRY

Simplified Form of Uniform Cost and Estimating System Together with Optional Method for Small Foundries



MALLEABLE IRON FOUNDRY INDUSTRY COST SYSTEM



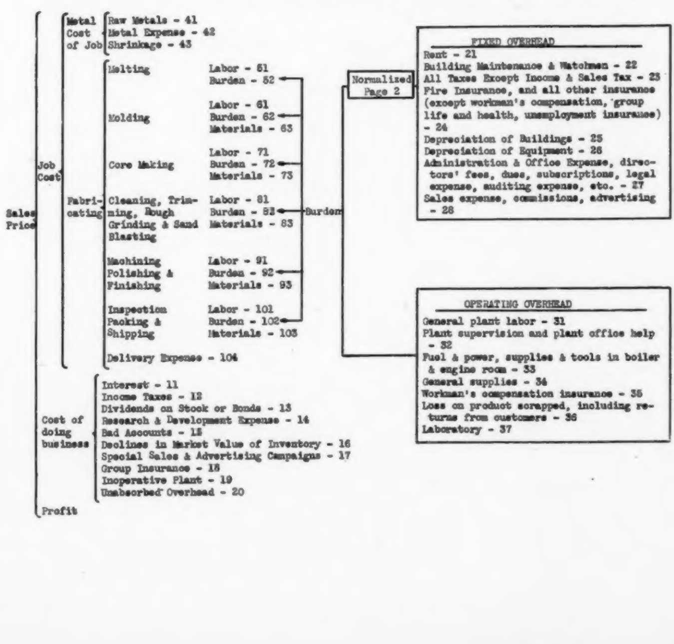
Discussion brought out that the Malleable Iron Industry had made a rather important change under the code as compared with the system in use preceding the code. The change constitutes primarily applying a greater percentage of the overhead on the basis of the weight of metal poured than had been practiced previously. This is a factor which must be reckoned with in the Malleable Iron Industry because of the low yield which, as pointed out, is an average of only 48 per cent of the metal poured and is, therefore, a prime factor in cost. This same problem, of course, applies to other types of foundry work where the yield is a low percentage of the weight of metal poured. The relation of good castings to the weight of metal poured or the weight of metal charged is something which must not be lost track of in determining accurate costs.

It was brought out that all four branches of the industry recognize in their cost systems that direct labor is a basis upon which

to distribute at least a portion of the overhead or burden. The A.F.A. membership is made up of all types of foundries and in many cases one member operates in two or more of the four branches of the foundry industry. There is no single organization other than the A.F.A. that reaches this type of member so far as his total production is concerned. To the extent that the A.F.A. through its Cost Committee can show the similarity between the cost systems in the four branches in the industry and make it possible for this member to use the recommended cost accounting procedure for his production, a real service will be rendered.

As proper estimating of prices is based primarily upon proper cost accounting procedure to accurately determine costs, it is obvious that estimating sheets or forms must be based upon cost systems. Good cost accounting in actual use and properly applied means good estimating. To the extent that the cost accounting systems are similar in the four branches of the foundry industry, then also will the estimating methods be similar. Methods of estimating not based upon adequate cost systems or adequate knowledge of costs, must obviously be on rather flimsy foundation and will invariably have a very limited application and may result in

NON-FERROUS FOUNDRY INDUSTRY COST SYSTEM



serious losses on certain jobs in production and such high prices on other jobs that business will be lost.

It was the consensus of the meeting and is the opinion of the Cost Committee that the Committee should endeavor to promote the use of uniform cost systems. The Committee may from time to time offer suggestions to the various branches of the foundry industry with regard to their cost systems. The members of the A.F.A. Cost Committee representing the various branches of the foundry industry will be the avenues through which the Cost Committee will cooperate with the various branches of the industry.

Program

The immediate program of work for the A.F.A. Cost Committee is, therefore, the preparation of new charts of the four foundry cost systems to show in simple form the basic fundamentals of these cost systems and the basic similarities between these different cost systems.

The membership of the Committee as now constituted consists of—

Sam Tour, Lucius Pitkin, Inc., 47 Fulton St., New York, N. Y., *Chairman.*

Peter E. Rentschler, President, Hamilton Foundry & Machine Co., Hamilton, Ohio—representing Gray Iron Foundry Industry.

Charles Anderson, President, Belle City Malleable Iron Co., Racine, Wis.—representing Malleable Iron Industry.

W. J. Corbett, Atlas Steel Casting Co., 1963 Elmwood Ave., Buffalo, N. Y.—representing Steel Foundry Industry.

James L. Wick, Jr., Falcon Bronze Co., Youngstown, Ohio—representing Non-Ferrous Foundry Industry.

C. E. Swank, Dayton Malleable Iron Co., P. O. Box 980, Dayton, Ohio—representing Malleable Iron Industry.

A. E. Grover, 29 Fourth Ave., Berea, Ohio.

Respectfully submitted

Sam Tour, *Chairman*

Founding Magnesium Alloys

By Dr. John A. Gann* and Manley E. Brooks,**
Midland, Mich.

Abstract

Lightness of materials has gradually become more important in industrial applications and especially in airplane manufacture. Magnesium alloys are the lightest weight of the present fabricating materials and are assuming an important place in industrial construction. In this paper, the authors outline the general methods used in the production of magnesium-alloy castings, taking up such subjects as melting, alloying, casting, finishing, and heat treatment. They also give a brief summary of the properties of magnesium alloys and some of their uses.

1. The commercial utilization of magnesium alloy castings, in many important industrial fields, warrants a more comprehensive description of the methods used in their production than is now available in American technical literature. The present paper will treat this subject primarily from the standpoint of the general methods used in the production of Dowmetal sand castings, beginning with melting, alloying, and casting; following on through heat treatment and surface finishing; and concluding with a brief summary of the properties and uses of this type of material. The more important steps in these procedures will be outlined but time and space do not permit a complete description of all the details that must be controlled in a well operated foundry.

2. Although many of the basic principles of foundry practice are common to most metals, differences in their physical and chemical properties necessitate marked changes in many details of operation. These properties, in the case of magnesium, are lightness and chemical activity, particularly in the molten state. Lightness has exerted a pronounced effect on melting, alloying,

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* Chief Metallurgist, The Dow Chemical Co.
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Note: This paper was presented at one of the sessions on Non-Ferrous Founding at the 1935 Convention of A.F.A. held in Toronto, Canada.

and casting practice; while chemical properties have had a marked influence on the development of melting and casting technique, as well as on cleaning and surface finishing.

MELTING PRACTICE

3. The first successful melting practice for magnesium developed in this country is known as the "Open Flux Pot Melting Practice." It has been used commercially for more than 15 years and is based on the use of a large bath of a fluid flux that

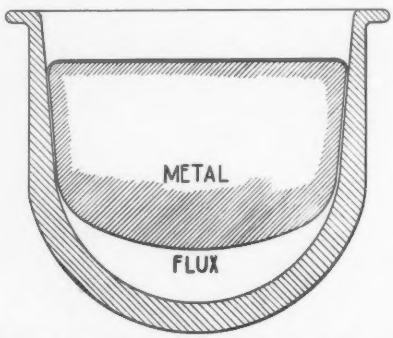

FIG. 1—THE MAIN BODY OF FLUX LIES IN A POOL AT THE BOTTOM OF THE POT BUT A THIN FILM IS FORMED BETWEEN THE METAL AND THE WALLS OF THE POT, AND ACROSS THE METAL SURFACE.

functions in a dual manner. This flux protects the molten metal from the air and furnace gases by completely enveloping it and, thereby, eliminates the dangers usually associated with prolonged holding of metal in the molten state and with overheating. It likewise purifies the metal by washing out nonmetallic impurities when the metal and flux are intimately mixed. The flux normally used consists of 60 per cent anhydrous magnesium chloride and 40 per cent sodium chloride, and has a specific gravity and surface tension that causes it to float the metal as shown in Fig. 1. The main body of flux lies in a pool at the bottom of the pot; but a thin film is formed between the metal and the walls of the pot, and across the surface of the metal.

Charges.

4. Melting pots are of low carbon cast steel. Cast iron is not leak-proof toward the flux and the heat resistant alloy steels do not show a service life commensurate with their cost. Plain

carbon steel pots are good for approximately 1000 hours of service. Their deterioration is due more to scaling on the outside of the pot rather than chemical attack from the flux on the inside. Pots holding 300 and 600 lb. of metal respectively are the sizes most generally used and are mounted in gas or oil fired brick settings as illustrated in Fig. 2.

5. The charge for the smaller pot consists of 100 to 125 lb. of flux and 300 lb. of metal, added in the order named. The flux has a lower melting point than the metal and soon forms a bath to receive the metal as it melts down. The molten charge is now

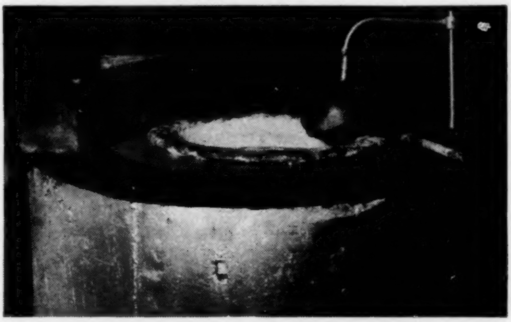

FIG. 2—POTS USUALLY ARE MOUNTED IN GAS OR OIL-FIRED, BRICK SETTINGS OF THE TYPE SHOWN. PUDDLING IS DONE WITH A SLUDGE LADLE, AS SHOWN, OR WITH A CASTING LADLE, SHOWN IN FIG. 8.

given a thorough puddling to bring metal and flux into intimate contact with each other, and thus insure complete removal of oxide and other nonmetallic impurities. Puddling is done with a sludge ladle, shown in Fig. 2, or with a casting ladle shown in Fig. 8. The contents of the pot are then allowed to stand quietly for several minutes in order that the impurities may settle from the metal and flux, and form a sludge at the bottom of the pot. Dry magnesium oxide is light and fluffy and shows little to no tendency to separate by gravity from the molten metal. It is readily wetted by the molten flux, however, whereupon it is compacted into dense sludge particles that settle to the bottom of the pot. The sludge is removed at regular intervals, generally once a day unless very large amounts of scrap metal are melted. It is dipped out with a sludge ladle (Fig. 2) and after pouring back the metal and supernatant flux in the ladle, the sludge is emptied into the sludge pans, likewise shown in Fig. 2.

Fluxing.

6. More metal is added as required to replace that removed in the production of castings. Each new charge is washed in flux as already described. While flux can be used repeatedly, there should always be enough present so that it can be readily brought to the surface of the metal during the puddling operation, and so that the casting ladle can be cleaned in the bath of flux below the metal as explained later. Under normal conditions, one pound of flux is required for each 8 to 12 lb. of metal melted; this ratio depending on whether ingot or scrap is melted.

7. All material added to a pot of molten metal should be carefully preheated in order that absorbed moisture may be completely driven off. The foundry flux is very hygroscopic and, hence, should be stored in covered containers and should not be added to a pot containing molten metal. This hygroscopicity likewise calls for careful preheating of all equipment, such as ladles, thermocouples, iron molds, and sludge pans.

SCRAP RECOVERY

8. Scrap recovery is of particular interest and importance in the magnesium foundry because of the technique involved and because of the quality of the recovered metal. Massive scrap, such as sprues, gates, and risers should be free from adhering sand and other contamination. They can be melted the same as ingot, except that the metal should be more thoroughly washed with flux. Metal skim-gates (see below under "Molding") will cause no harm in the pot and can be dipped out with the sludge. In the case of poor quality scrap, it is good practice to use two pots on the counter-current principle, namely, to melt in the one containing the older and dirtier flux and after a preliminary wash to transfer the metal to the casting pot containing clean flux and wash again.

Machine Shop Scrap.

9. Machine shop scrap, such as shavings, borings, chippings, etc. present a different problem because of the greater ease with which such finely divided metal can be ignited and because of the high ratio of surface oxide to metal. Obviously, this type of scrap should be kept dry and, preferably, free from oil or other cutting compounds. The practical solution of the shaving re-

covery problem consists in melting down the shavings at the lowest possible temperature, using plenty of flux, and starting with a pot containing some metal in the pasty or semi-molten condition. A shovel full of shavings is then added and quickly stirred into the flux. Stirring is not difficult because of the molten condition of the flux. The heat supply of the pot and the addition of shavings are so controlled that the metal in the pot remains semi-fluid. This low temperature operation practically eliminates any loss due to burning and gives maximum coalesence of the metal.

10. If the temperature were appreciably above the melting point of the metal, many of the chips would melt into individual globules and coalesence would be hindered by the tenacious dirt film surrounding each globule and by the ease with which such globules glide by each other when stirred with the flux. Crystals in the semi-solid globules, however, puncture this film of flux and permit coalesence. When sufficient shavings have been added to fill the pot, the charge is gently stirred to complete coalesence and the temperature then raised to 1300 to 1350 degrees Fahr. for the regular puddling or washing operations. The pot contents are now allowed to stand quietly for a few minutes to allow the sludge to settle, whereupon the metal is poured into ingots or transferred to the casting pot.

Remelt Properties.

11. If the melting and purification of scrap is conducted properly, the recovered magnesium alloy is equivalent to virgin metal. A comparison of the properties of virgin alloy and remelted scrap is shown in Table 1. One hundred pounds of virgin

Table 1

Effect of Remelting Dowmetal A

Melt Number	Tensile Strength lb. per sq. in.	Elongation Per Cent	Impact [1] Dow No.
Orig.	26,500	5.9	5.8
5	26,900	6.1	4.5
10	27,400	6.5	5.2
15	26,500	6.0	4.6
Avg. 1–15	26,900	6.0	4.9

[1] Dow impact numbers represent ft.-lb. of energy absorbed in breaking a ½ in. square specimen with a ⅛ in. deep notch cut on a 1/16 in. radius. These values are approximately twice the standard Izod impact numbers.

ingot were melted and about two-thirds of it cast into sand molds. These castings were then remelted and recast until the cycle had been repeated 15 times. Test specimens were poured from each heat, and the data shows that, within normal tolerance limits, the properties are constant throughout the entire run. On the other hand, if the remelted scrap is not properly washed with flux, the oxide skins on ingot and scrap are not removed but soon accumulate to such an extent that they make the metal viscuous and difficult to cast, and likewise reduce the strength of the metal. Contamination by foreign metals must be carefully avoided since many of these contain copper or nickel, two metals that are very detrimental to magnesium from the standpoint of corrosion resistance.

ALLOYING

12. Substantially all Dowmetal castings are now made from the magnesium-aluminum-manganese and magnesium-aluminum-manganese-zinc groups of alloys. Aluminum and zinc alloy so readily that hardeners and special technique are not required. Manganese alloys more slowly and only to a limited extent. It is generally added in the form of a 90-10 aluminum-manganese hardener. The casting alloys normally contain 0.2 to 0.4 per cent manganese but since this represents approximately the solubility limit, more time and stirring are required than when alloying other metals. A 75 to 80 per cent alloying efficiency for manganese is considered good operating practice. Most of the excess of unalloyed manganese settles to the bottom of the pot, although a few particles of microscopic size remain suspended in the alloy. The alloying ingredients are placed in the ladle and then submerged and gently agitated in the molten magnesium, after which the entire charge is thoroughly stirred.

13. The aluminum content of magnesium-aluminum-manganese alloys and of the magnesium-aluminum-manganese-zinc alloys, before the introduction of the zinc, can be controlled with sufficient accuracy for most commercial work by determining the Rockwell hardness of specially prepared samples. The metal is cast into a preheated graphite mold as illustrated in Fig. 3. Samples one-half inch long are cut from the center of the two middle one-half inch square bars and polished on both ends, finishing with 150 emery cloth.

14. Rockwell "E" hardness readings are then made on each

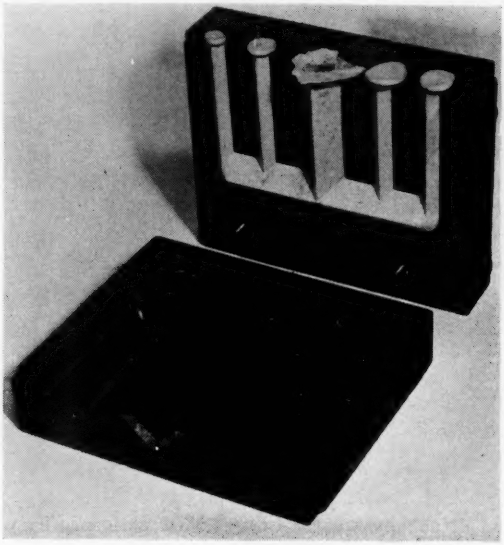

Fig. 3—Preheated Graphite Mold Used to Cast Samples for Control of Aluminum Content in Magnesium Alloys.

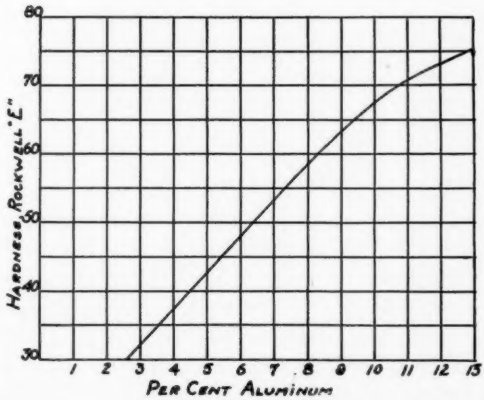

Fig. 4—Chart Showing Relation Between Rockwell "E" Hardness and Per Cent Aluminum in Magnesium-Aluminum-Manganese Alloys.

surface about $\frac{1}{8}$-in. from the corners of the specimen. Readings are rejected if they are two or more points removed from any of the other values, and a new sample is run if three or more readings are rejected on a single specimen. The average Rockwell "E" hardness value is then used for the determination of the percentage of aluminum from the graph shown in Fig. 4. The aluminum content thus obtained is usually correct to ± 0.3 per cent. This procedure is very helpful, particularly when melting scrap from alloys containing different amounts of aluminum as it constitutes a quick method for determining the amounts of the different ingredients required to bring the molten charge to the desired composition. After casting into ingots, the metal can be analyzed by standard chemical methods if more accurate data are required.

MOLDING

15. The casting of magnesium in green sand molds became practical with the discovery of methods for protecting the hot metal from attack by water vapor. This action is so vigorous in ordinary wet sand that the surface and sometimes the entire cross-section of the castings are badly oxidized. Such burning can be completely overcome, however, by incorporating in the sand, substances that are more readily oxidized than the magnesium itself or that form a protective gas blanket around the metal. These materials are commonly known as "Sand Addition Agents" and include sulphur, boric acid, and certain ammonium salts, particularly the fluorides. The amount used depends upon the agent selected, the permeability and moisture content of the sand, and the thickness of the cast section. Some foundries prefer simple mixtures of sulphur and boric acid, while others employ ammonium fluoride salts, alone or mixed with sulphur and boric acid. The heap becomes depleted on continued use so that fresh additions are made from time to time as required to prevent burning. With heavy castings or sand of relatively low permeability, it is sometimes advantageous to use a facing containing more of the agent, to dust the molds with finely powdered sulphur, or to surface dry the mold; otherwise, special facings and washes are not required.

Sand Practices.

16. An open molding sand should be used to offset the light-

ness of the metal and allow the gas to readily escape. Very satisfactory results are now being obtained from a synthetic sand with an A.F.A. permeability of 50 to 60, prepared by adding 4 per cent bentonite to a silica sand graded to a 100 to 150 mesh. A 75-25 water-glycol mixture is used as the tempering agent. Glycol functions much the same as water in developing the molding characteristics of sand and, hence, lowers the actual water content of the tempered sand. It likewise exerts some protective action towards the magnesium and because of its high boiling point prevents rapid drying out of the sand on the surface of the heap. In practice, the glycol is added to the sand and the tempering completed by the addition of the requisite amount of water. Thorough mulling of the sand is essential in order to insure uniform distribution of the bentonite, glycol, and sand addition agent and to improve the strength and plasticity of the sand.

Ramming.

17. The sand should not be hard-rammed close to the pattern; but as one proceeds away from the pattern, the ramming can be increased to insure safe handling of the mold without danger of drops. Light ramming improves the permeability of the sand and permits its contraction during the solidification and cooling of the castings. This contractability in both molds and cores is desirable to counteract hot-shortness in the alloys and so minimize the danger of shrinkage cracks. The mold should likewise be freely vented to aid in the escape of gases.

Gating Practices.

18. Although gating practice varies necessarily from casting to casting, there are a number of fundamental principles that must be observed. The metal should, in general, enter the mold cavity at a low point with a minimum of splashing or turbulence, since mechanically entrapped gas forms oxide skins in the metal and these, in turn, increase the viscosity of the metal and retard any subsequent escape of gas. In some cases, however, it is advisable to enter the metal at the center or top providing the mold cavity has an incline to break the velocity, and is without elevations and depressions that will create a turbulence before the metal reaches the bottom. This procedure often results in a more

uniform solidification of the casting, thus helping to eliminate shrinks, cracks, porous sections, and in some cases misruns.

Skim Gates.

19. Turbulence, with its resulting evils, is largely overcome through the use of perforated sheet-metal skim-gates containing eight or twelve perforations per inch. This screen is placed at the bottom of the sprue, and, in large complicated castings, a second screen is sometimes placed in the runner near the gates. These screens choke the flow of metal, thereby assuring a steady feed into the mold cavity, and they likewise trap oxide skins that form on the surface of the metal during the pouring operations. Figure 5 shows a mold just prior to closing with the screen in place. Wedge gates that are wide and shallow and feed from the bottom of a hump or well likewise aid in the removal of entrapped air and oxide skins but are less frequently used now that skim gates are so generally employed.

20. A number of finger gates are preferable to fewer large ones as they give a better distribution of heat in the casting and also prevent local overheating of the sand and generation of excess gas and water vapor. Similar objectives call for the location of gates on the thinner sections of the castings. Although the specific heat of the metal is high (0.33 avg. specific heat 70

FIG. 5—OPEN MOLD FOR MAGNESIUM-ALLOY CASTING SHOWING GATING METHODS AND SKIMMERS IN THE GATE IN PLACE.

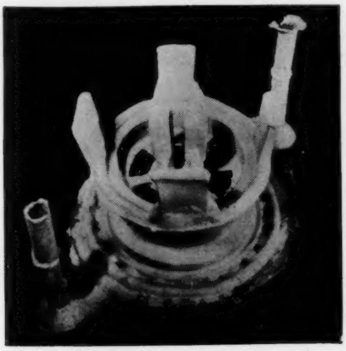

Fig. 6—Casting with Gates and Risers Attached.

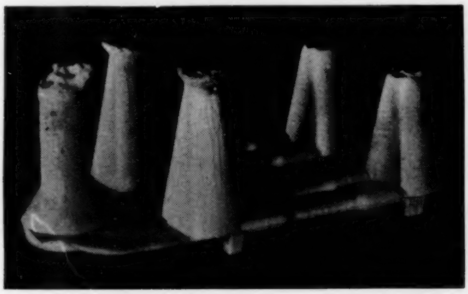

Fig. 7—Method of Gating Tension Test Specimen.

to 1200 degrees Fahr.), the gravity of the metal is low, so that the total heat per unit volume is also low. As a result, gates and runners should be of generous proportions to insure a free flow of metal, and risers should be large and connected as directly as possible to the section to be fed. Figure 6 shows a casting with gates and risers attached and Fig. 7 shows the method of gating tension test specimen.

Progressive Solidification.

21. Progressive solidification of the metal should be obtained through the use of risers instead of chills wherever the riser will accomplish the same end, and provided it is located so that it does not introduce trouble in molding and trimming. When chills are used, they may be made from customary materials, such as iron and graphite, although best results are obtained from

magnesium alloy chills. The chills must be clean and dry to avoid blows, and large chills should be perforated to aid in the escape of gas.

Shrinkage Allowance.

22. A shrinkage factor of 3/16 in. per ft. is used for Dowmetal castings of moderate size or with unrestricted shrinkage. A shrinkage factor of 5/32 in. per ft. is advisable on large castings or where free shrinkage is prevented by bosses or internal cores. As these values compare very closely with the shrinkage values for aluminum alloys, equipment designed for aluminum can be used in a majority of cases. Generous fillets should be used where the gate joins the casting and where thin sections join heavy sections.

CORES

23. Cores should be made from an open sand containing sulphur, boric acid, and an oil binder. They should be rammed no harder than necessary to insure retaining their shape before baking, and should be well vented. The oil binder should generate a minimum of gas and should permit the core to soften when contacted by molten metal. The cores are baked at 350 to 500 degrees Fahr. for 20 minutes to several hours, depending on the size of the core, after which they are given a graphite-alcohol wash and the alcohol ignited and burned off.

24. Green sand cores should be used wherever possible for smoothness and economy. They are made from the regular heap used for the production of molds.

DIPPING AND POURING

25. In the earlier part of this paper, we described the melting, alloying, and purification operations and left the metal in the pot ready for casting. The lowest possible pouring temperature should always be used as this will insure sounder castings with maximum physical properties and will help reduce melting losses. Temperature control can occur in the pot or in the ladle, depending on whether a single type of casting or a variety of castings requiring different temperatures are being poured. Iron-constantin thermocouples are very satisfactory. These are prepared by welding a constantin wire to the inside tip of a closed thin-walled iron tube.

Ladles.

26. The casting ladle shown in Fig. 8 has a parting sweep, retaining shield, and under-feed pouring spout. The sweep is used to part the film of flux covering the surface of the metal in the pot and to permit the dipping of clean metal. Oxide films that form on the surface of the metal in the ladle are held back by the retaining shield. The entrance to the underfeed pouring spout is a short distance from the bottom of the pouring ladle

Fig. 8—Type of Casting Ladle Used for Magnesium Alloys.

and is provided with a flange, thus retaining in the ladle any small amount of flux that may have been dipped with the metal.

27. Prior to pouring, the ladle is preheated and cleaned by washing in the flux underneath the metal at the bottom of the pot. After inverting and draining the ladle, it is rinsed two or three times with metal. This is accomplished by parting and skimming back the flux from a small area on the surface of the metal. The edge of the ladle is held slightly below the surface, whereupon clean metal flows into the ladle. Part of this metal is poured through the spout and the balance is poured rapidly out of the back of the ladle. The clean ladle is then filled with metal for casting as previously described in rinsing. If the flux film does not automatically reform as the ladle is lifted from the metal, the exposed surface is protected by sprinkling with

powdered flux, or a mixture of anhydrous flake magnesium chloride and salt.

28. Surface oxidation of the metal in the ladle is minimized by dusting on a mixture of sulphur and ammonium fluoride salts. Any excess metal in the ladle, above that required for the casting, is poured back into the pot near its circumference. The ladle can be used repeatedly until fouled by adhering magnesium oxide, whereupon it is cleaned in flux.

Pouring.

29. When pouring a mold, the lip of the ladle is held quite close to the mouth of the sprue and the stream of metal is maintained as steady as possible to minimize turbulence and entrapping of gas. When the casting must be poured hot or when a large sprue is required, the surface of the metal in the sprue may start to burn. Such fires, or those caused by accidents such as runouts or spills on the foundry floor, are readily extinguished by covering with regular molding sand.

CLEANING AND FINISHING

30. Castings are rough-trimmed to remove sprues, gates, and risers; sand blasted; and given a first inspection prior to heat treatment. Final clean-up generally follows the heat treating operations. Band saws, made from 20-gauge spring temper steel with 4 teeth per inch, are operated at a speed of approximately 4,000 ft. per min. Power hack saws should have 10 teeth per in. and hand hack saws 14 teeth per in. Single-cut files are recommended and the type known as "body worker's" files are quite satisfactory for heavy work. Portable electric or pneumatic chippers, rotary files, and grinders are used to good advantage. Medium-hard grinding wheels (K to M for alundum) are recommended. A grain size of approximately 20 is satisfactory for foundry snagging operations while a grain size of 30 to 46 is best for more accurate work.

Precautionary Measures.

31. Tools used on magnesium alloys should not be used for other metals in order to avoid the danger of sparks. This is particularly true with grinders due to the inflammability of the powder. Special precautions should, therefore, be taken to see

that all skim gates and core wires are removed from the castings before grinding and that the wheels do not touch steel inserts. Operators' clothing should be of smooth cloth with no pockets or cuffs in which dust can collect. The grinding wheels and the floor around them should likewise be kept free from dust, preferably through the use of a suction exhaust system. If proper precautions are observed, the fire risk is small and if ignition should occur the flame will be confined to a minimum of material. Regular molding sand will quickly extinguish any fire that does start. Graphite, table salt, or cast iron borings should be used in case of fire in the machine shop or around equipment that might be damaged by the abrasiveness of sand.

Machinability.

32. One of the outstanding characteristics of magnesium alloys is their remarkable machinability which is better than that of any other common metal. Machining operations are carried out on standard machines equipped with plain carbon or alloy steel tools, usually the former. Where care is exercised to see that the tools are sharp and have the proper clearance, the machines can be run at maximum capacity. Cuts as heavy as 1/2 inch with feeds of 20 in. per min. and speeds of 700 ft. per min. have been used. Light finishing cuts have been made at speeds of 1400 ft. per min.

Welding.

33. Welding and soldering of castings are not common practices in the magnesium foundry as with some other metals, although these operations may be used to repair small surface defects in unstressed sections of certain types of castings. In acetylene welding, the casting should be heated to 600 to 750 degrees Fahr. The filler rod should be of the same general composition as the casting, and a flux should be used. (Dow Flux No. 45, Alcoa Flux No. 22, etc.) The completed welds should be thoroughly cleaned in the chrome-pickle solution (see below under "Painting") and rinsed in water to remove any adhering flux.

Soldering.

34. Castings to be soldered should be thoroughly cleaned by wire-brushing, chipping, or filing so as to present a clean surface to which the solder can bond. They are then preheated to 300

to 400 degrees Fahr. and the solder vigorously puddled with a sharp-pointed steel tool until it has alloyed with the magnesium. Suitable soldering materials include 90 cadmium—10 zinc or 60 cadmium—30 zinc—10 tin. The former is less brittle but requires a somewhat higher temperature.

35. Magnesium castings are normally sound and free from pinholes and coarse porosity. Where pressure-tight requirements must be met, as for example in the case of certain pneumatic tool parts, the castings may be impregnated with china wood oil if necessary. The process consists of a partial evacuation of the container with its charge of oil and castings, followed by the application of pressure to force the oil into any microscopic pores in the surface of the metal. Polymerization, or fixing the oil in the pores, is accomplished by heating the castings in an engine oil bath at approximately 250 degrees Fahr. A subsequent kerosene wash removes adhering engine oil.

HEAT TREATMENT

36. All of the present Dowmetal sand casting alloys are amenable to heat treatment with marked improvements in mechanical properties. Both the solution and the precipitation methods are used, depending on properties required. The solution heat treatment (H. T. No. 1) of the Mg-Al-Mn alloys consists of 16 hrs. heating at 775 degrees Fahr. It increases the tensile strength, toughness, and percentage elongation of the alloys. The smaller percentage aluminum in the Mg-Al-Mn-Zn alloys permits a lower heat treating temperature (H. T. No. 1a) and this is desirable to avoid the hot-short temperature zone.

37. The aging or precipitation heat treatment (H. T. No. 3 and H. T. No. 3a) is given to the solution heat treated material and in both types of alloys is substantially complete after 16 hours at 350 degrees Fahr. This treatment raises the yield strength and hardness of the alloys with a lowering of ductility and toughness. Properties intermediate between those of the solution heat treated and the fully aged conditions are sometimes desired and can be obtained by giving the alloy a partial or short-time precipitation heat treatment (H. T. No. 2 and 2a). The successful heat treatment of the Mg-Al-Mn-Zn type of alloy has been a decided factor in causing this alloy to partially supplant the older Mg-Al-Mn compositions. It yields a combination of properties together with improved corrosion resistance heretofore not obtained on magnesium

alloys. The properties of these different alloys in the more widely used conditions are given in Table 2.

38. Accurate temperature control is very important in heat treatment, the same as with many other metals. This is particularly true with the solution heat treatment which is carried out at a temperature close to the softening point of the alloy. Electrically heated ovens equipped with automatic temperature control and fans that give periodic reversals in direction of the circulating atmosphere insure the proper temperature regulation.

Painting

39. Magnesium alloys are remarkably stable under ordinary conditions of exposure and in many cases require no painting. However, in view of the fact that it is difficult to control the location and service conditions of any given article, most castings are given suitable paint coatings.

40. Prior to painting, the metal surface must be cleaned to remove adhering dirt and grease and then given a chemical treatment to insure best results. Oxide films and dirt are generally removed mechanically by sand blasting or wire brushing. Oil and grease are removed by washing with a solvent, such as carbon tetrachloride or gasoline, or are removed by treatment in hot alkaline cleaners. The immunity of magnesium alloys to alkalies permits the use of strong alkaline cleaners as used on steel. This treatment is best conducted at the boiling temperature and should be followed by a thorough washing in hot water.

41. Cleaned castings are then given the chrome-pickle treatment. This consists of a $\frac{1}{2}$ to 2 minute dip in a solution containing 1.5 lb. of sodium bichromate and 1.5 pints of concentrated nitric acid per gallon of solution. Upon removal from this bath, the castings are allowed to drain for a few seconds and then thoroughly washed in hot water. This treatment improves the corrosion resistance of the metal and gives an excellent "tooth" which increases the adhesion of subsequent paint coatings.

42. The successful painting of magnesium castings offers no unusual difficulties where approved materials are used and good painting practice is observed. The selection of the primer is very important in view of the fact that all representatives of a given class of paints do not show the same service performance. Vehicles with maximum imperviousness to water are best, particularly where castings will be exposed to severe corrosion condi-

Table 2

PROPERTIES OF CAST AND HEAT TREATED DOWMETAL ALLOYS

Alloy	Composition Mg	Al	Mn	Zn	Condition	Tensile Strength, lb. per sq. in.	Yield Strength (set:0.2), lb. per sq. in.	Elongation in 2 in., per cent	Compressive Strength, lb. per sq. in.	Shear Strength, lb. per sq. in.	Rockwell "E" Hardness	Brinell Hardness	Impact Izod, ft.-lb.	Fatigue Endurance Limit, lb. per sq. in.
A	Remainder	8.0	0.2	...	As-cast	24,000—28,000	10,000—13,000	3—7	44,000—48,000	16,000—18,000	53—60	47—51	2—4	6,000—8,000
					H.T. No. 1	32,000—36,000	10,000—13,000	8—12	44,000—48,000	16,000—18,000	53—59	47—50	5—7	6,000—8,000
G	Remainder	10.0	0.1	...	As-cast	21,000—24,000	12,000—15,000	1—3	47,000—50,000	16,000—18,000	62—68	52—57	1—3	8,000—10,000
					H.T. No. 1	30,000—35,000	11,000—14,000	6—9	48,000—52,000	18,000—20,000	58—66	49—55	3—6	9,000—11,000
					H.T. No. 3	31,000—36,000	17,000—21,000	1—4	52,000—57,000	20,000—22,000	76—84	65—75	1—3	8,000—10,000
B	Remainder	12.0	0.1	...	As-cast	19,000—23,000	15,000—17,000	0—1	45,000—49,000	15,000—17,000	69—73	57—61	0.5-2	....
					H.T. No. 3	27,000—32,000	20,000—24,000	0—1	52,000—57,000	17,000—19,000	82—90	72—85	0.5-2	....
H	Remainder	6.0	0.2	3.0	As-cast	25,000—30,000	11,000—13,000	4—8	....	....	54—61	47—51	2—5	9,000—11,000
					H.T. No. 1a	33,000—38,000	11,000—14,000	9—13	....	....	59—64	50—53	4—6	9,000—11,000
					H.T. No. 3a	37,000—42,000	18,000—21,000	3—7	....	....	76—82	65—72	1—3	9,000—11,000

Yield strength is defined as the stress at which the stress-strain curve deviates 0.2 per cent from the modulus line.
Modulus of elasticity of Dowmetal is 6,500,000 lb. per sq. in.
Tensile and hardness values are obtained on standard unmachined 0.5 in. diameter tension test specimens.
Compression and shear values are obtained on ¾ in. diameter specimens machined from 1 in. diameter bars.
Fatigue endurance values are obtained on R. R. Moore machines using specimens machined from ⅝ in. diameter bars.
Impact values are obtained on Izod type specimens cast in a graphite mold. Specimens are 10 millimeters square with a 45 degree notch having a depth of 2 millimeters and a radius at the bottom of 0.25 millimeter, according to A.S.T.M. Tentative Standard E23-33T.

tions. Zinc chromate pigments in the primer are usually beneficial in service near salt water or continuous moist air. Baking primers are recommended on small castings because of their excellent adhesion. The choice of surfacer and finish coats is likewise important, although perhaps not so exacting as in the case of primers. Full synthetic and oil base synthetic enamels represent the better class of products, particularly for outdoor service. General recommendations tend to be abstract and indefinite, while a specific recommendation would appear to favor one particular paint product. As a result, the user of magnesium castings would do well to obtain the correct paint schedule for his purpose from those companies who have studied this subject.

PROPERTIES AND USES

43. Lightness is the outstanding characteristic of magnesium alloys and is largely responsible for many of their present uses. An ever increasing number of industries are based on the possibilities of light weight construction. This is especially true in the fields of transportation and portable equipment. Magnesium alloys have inherently good strength properties and, when likewise considered from the standpoint of lightness, are found to possess strength-weight ratios distinctly superior to those obtained with most other cast metals. Table 2 gives the properties of our present Dowmetal casting alloys in the as-cast and heat treated conditions. These data are based on values obtained from test specimens cast as illustrated in Fig. 7. Tension specimens cut from commercial castings average about 75 per cent of the strength of separately cast bars. The alloys in the as-cast condition are satisfactory for a wide variety of applications but they are heat treated when service conditions demand maximum strength. Table 3 compares these magnesium alloys with other cast metals. The specific strength data in the last three columns are of special interest to us as they show the superiority of magnesium alloys when maximum strength per unit weight is required.

44. Lightness is also an important factor in determining the cost of castings. Ingot metals are usually sold on a weight basis, but in castings the volume is established and the corresponding weight depends on the gravity of the metal. Figure 9 shows that although magnesium is more expensive on the basis of cost per pound than some of the other metals used in the production of

Table 3

PROPERTIES OF CAST METALS

Material	Specific Gravity	Weight, lb. per cu. ft.	Tensile Strength, lb. per sq. in.	Yield Strength, lb. per sq. in.	Modulus of Elasticity, lb. per sq. in.	Fatigue Endurance Limit, lb. per sq. in.	Impact Izod, ft.-lb.	Coefficient of Thermal Expansion per °F	Thermal Conductivity, C.G.S. Units	Specific [1] Tensile Strength	Specific [1] Yield Strength	Specific [1] Fatigue Endurance Limit
Dowmetal A (H. T. No. 1).....	1.80	112	34,000	12,000	6,500,000	7,000	6	0.000016	0.18	18,900	6,700	3,900
Dowmetal H (H. T. No. 3a)...	1.83	113	40,000	20,000	6,500,000	10,000	2	0.000016	....	21,800	10,900	5,500
Aluminum—Copper Alloy, SAE 38 (Heat Treated)............	2.77	174	36,000	22,000	10,000,000	6,000	3	0.000013	....	13,000	7,900	2,200
Aluminum—Copper Alloy No. 12 (SAE 30).....................	2.83	178	22,000	14,000	10,000,000	7,500	1	0.000013	0.30	7,800	5,000	2,700
Gray Cast Iron (Class 40 A.S.T.M. Tentative Specification A48-35T.)	7.2	450	40,000	......	18,000,000	20,000	....	0.0000060	0.10	5,600	......	2,800
Cast Steel (0.30 Per Cent C., Annealed)....................	7.86	490	76,000	42,000	29,000,000	33,000	21	0.0000066	0.12	9,700	5,300	4,200
Yellow Brass (70-30)............	8.4	525	40,000	......	13,000,000	18,000	....	0.000011	0.20	4,800	......	2,100
Monel Metal....................	8.80	550	72,000	35,000	25,500,000	......	....	0.0000083	0.6	8,200	4,000	......

[1] The specific tensile strength, specific yield strength, and specific fatigue endurance limit are equal to the tensile strength, yield strength, and fatigue endurance limit respectively in lb. per sq. in. divided by the specific gravity.

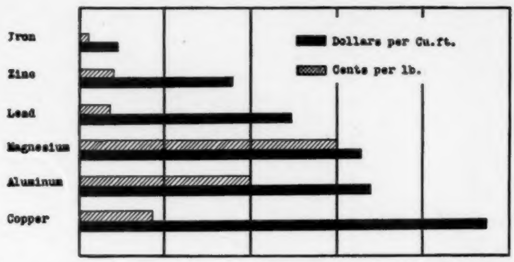

FIG. 9—COST OF VARIOUS PURE METALS ON POUND AND VOLUME BASIS.

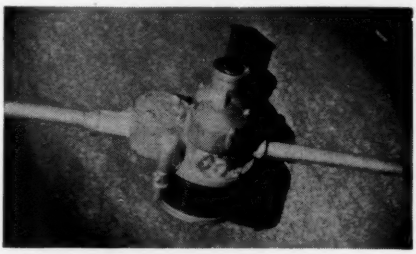

FIG. 10—PORTABLE MINE DRILL USING DOWMETAL CASTINGS.

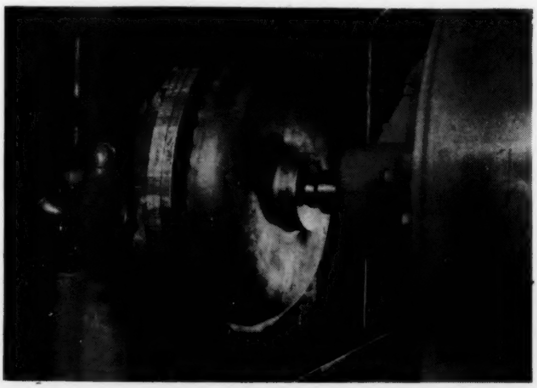

FIG. 11—HYDRAULIC COUPLING, 43-IN. DIAMETER, FOR VARIABLE-SPEED BLOWER.

casting alloys, it ranks very favorably when figured on the basis of cost per unit volume.

45. The user of magnesium castings is often able to capitalize on the excellent machinability of this metal since this characteristic sometimes permits the obtaining of finished castings at a lower figure than when made from some other metal with a lower basic price per pound. This is particularly true when machining costs constitute a large percentage of the total cost. In addition to the high speed permissible in machining operations, the power consumption per cubic inch of metal removed is less than with other metals recognized as having good machining qualities, such as bearing bronze and brass screw machine stock. The data in Table 4 were obtained by a company manufacturing high grade automatic machinery and constitute an actual example of such saving. Further economies in the use of these light weight castings are brought about by the ease of assembly, the increased life of the driving mechanism, and the reduced power consumption.

46. Typical applications of magnesium alloys include aircraft parts, such as crank cases, starting equipment, instrument housings, landing and tail wheels, and landing gear assembly; handles, motor cases, and different coverings in portable electric and pneumatic tools; appliances for office equipment; reciprocating and rotating parts on textile, packaging, and conveying equipment; safety blocks for sheet metal presses; and foundry equipment, such as flasks, match plate patterns, core boxes, and core setting jigs.

Table 4

RELATIVE MACHINING COSTS

Casting		Material Cost	Labor Cost	Total Cost	Saving in Cost
A	Cast Iron	$ 8.30	$66.62	$74.92	
	Dowmetal	29.04	40.53	69.57	$5.35
B	Cast Iron	9.05	66.97	76.02	
	Dowmetal	30.10	41.00	71.10	4.92
C	Cast Iron	0.75	7.00	7.75	
	Dowmetal	2.69	5.00	7.69	0.06
D	Cast Iron	0.83	8.00	8.83	
	Dowmetal	2.08	6.00	8.08	0.75
E	Cast Iron	2.80	41.00	43.80	
	Dowmetal	8.50	32.00	40.50	3.30

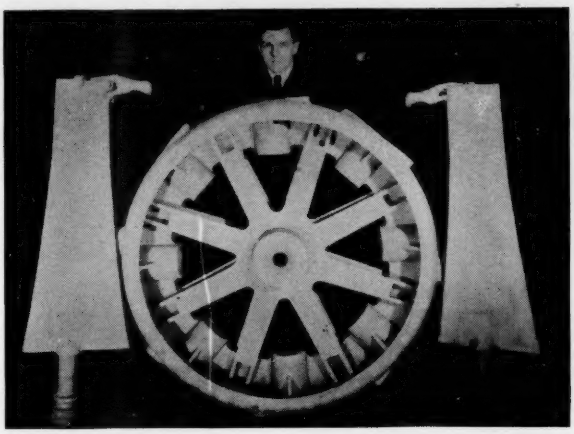

Fig. 12—Hub and Two Blades for a 12-Ft. Fan in Radio City Cooling Tower.

A few of these applications are illustrated in Figs. 10 through 15. These uses of magnesium castings are supplemented by other magnesium alloys in the form of sheet, forgings, and structural shapes which possess the same basic characteristics,—lightness, machinability, and high strength-weight ratio, that are present in the castings.

47. Magnesium alloy castings have been produced in the United States for approximately 16 years. Accurate production data are not available for the first 8 years, but Government reports for the past 8 years show a steady increase in annual production (except for a slight drop in 1930), resulting in a 1934 production

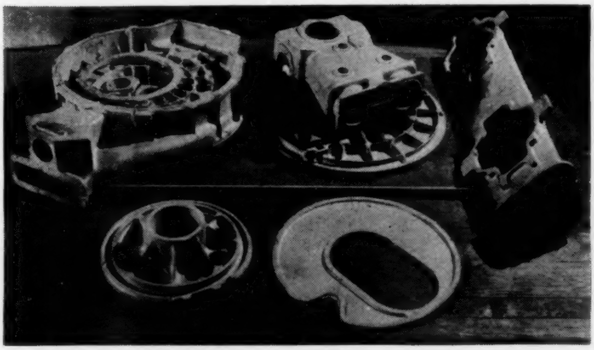

Fig. 13—Group of Aircraft Castings—Courtesy, Wright Aeronautical Corp.

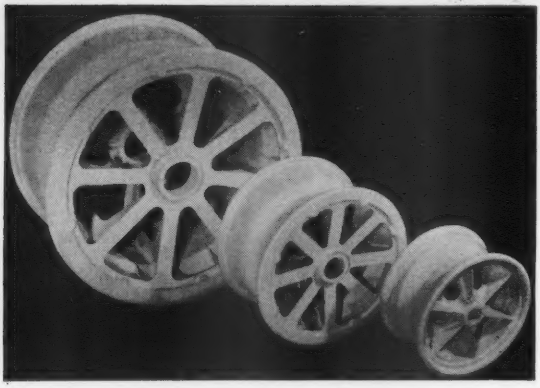

FIG. 14—AIRCRAFT LANDING WHEELS—10 TO 30-IN. DIAMETER.

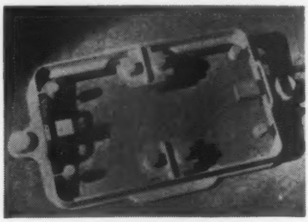

FIG. 15—CORE-SETTING JIG.

nine times as large as that of 1927. Numerous factors are responsible for this rapid expansion, including the availability of commercial alloys and methods of fabricating them. More important, however, is the rapid disappearance of prejudice and inertia that so often oppose the introduction and use of a new material, and their replacement by service tests that prove the dependability of these magnesium alloys.

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